Study S-186

A DAMAGE-LIMITING SHELTER-ALLOCATION STRATEGY

Grace J. Kelleher

INSTITUTE FOR DEFENSE ANALYSES
ECONOMIC AND POLITICAL STUDIES DIVISION

April 1965

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Contract OCD-OS-63-134
Subtask 4113-C

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FOREWORD

The work reported in this Study is part of a continuing effort in the analyses of alternative civil-defense systems by the Institute for Defense Analyses under Contract No. OCD-OS-63-134 (dated June 28, 1963) with the Office of Civil Defense, Department of the Army. The studies are being performed in the Economic and Political Studies Division of IDA.

This Study sets forth a damage-limiting strategy for allocating blast and fallout shelters to the inhabitants of a city or metropolitan area. For a given weapon, a method is outlined for ensuring that fatalities within any local area under study do not exceed a prescribed proportion of total population irrespective of the actual ground zero within that area. Alternative means of achieving this objective are considered and a least-cost method developed.

The proposed population protection method was initially conceived in June 1964 and was tested that summer using desk calculators. The results substantiated the feasibility of the strategy as well as its cost/effectiveness potential.

I would like to acknowledge with appreciation the contributions of other members of the EPSD staff who so ably assisted in this effort: Martha Strayhorn, who assisted in conducting the pilot test of the shelter allocation procedure last summer; Jane-Ping Crane, John D. Wells, and Jane Gleason, who developed the initial computer model, wrote the program specifications provided in Appendix B and supervised the production runs required for this study report; and Phyllis Weiner, who performed all of the technical secretarial

duties involved in the development and publication of this Study. Finally, I would like to thank Samuel E. Eastman, the Civil Defense Project Leader, for his support and encouragement throughout this research effort.

Grace J. Kelleher

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SUMMARY

A damage-limiting strategy for allocating blast and fallout shelter protection is proposed in this Study. The features which combine to make this strategy unique are its relatively fine-grained local orientation and its ability to meet a survival percentage criterion irrespective of the actual ground zero within the area considered.

Population distributions vary from city to city and must be considered in detail--not as averages or aggregates--in order to provide realistic, optimal protection for any one city. The strategy proposed here tailors shelter postures to the conditions and needs of individual cities or local areas. This local approach could be used to develop a national shelter program evaluating the needs of many cities by serial application of the shelter allocation model.

Shelter postures produced under this strategy consider all potential ground zeros within the protected area as part of the shelter allocation process; thus, fatalities from immediate blast effects and fallout are limited to a stipulated level, irrespective of where an assumed weapon might be delivered within a target city.

Costs are minimized in the shelter allocation process by following three specific decision rules described in Section II.

The results of pilot studies reported in Section III confirm that shelter postures developed under this damage-limiting strategy can make it possible to limit fatalities to a stipulated level[1] regardless of where the weapon may be delivered within a target

1. Subject, of course, to any errors involved in current estimates of basic phenomena and effects of nuclear weapons.

city. These studies also established that, by judiciously assigning shelters of various strengths to different areas of a city, the level of fatalities can be limited to that resulting when the strongest shelters under consideration are provided universally (at much greater cost) and the weapon detonated at the enemy's best aimpoint. For example, a mixed-shelter posture comprising 300- and 100-psi blast shelters and fallout shelters having a protection factor[1] (PF) of 40 or greater can limit fatalities to 2.2 percent, given a 10-Mt surface burst on the Houston at-home population. This posture costs only $548 million, yet guarantees the same minimum survival level as a posture providing 300-psi protection to everyone at a cost of $1,014 million. Similarly, for the same attack, a posture of 100-psi blast shelters and fallout shelters with a PF of at least 40 can limit fatalities to 5 percent at a cost of only $393 million. A posture providing 100-psi protection to everyone would guarantee the same minimum survival level at a cost of $562 million.

The shelter allocation model is described in Section II and specifications for computer adaptation are provided in Appendix B. Conclusions of this Study and recommendations for further development of the model are set forth in Section IV.

1. The protection factor of a shelter is a measure of its ability to attenuate radiation. It is the ratio of the dose which would be received outdoors, without any protection, to that received at a particular location in a structure.

I

INTRODUCTION

Earlier civil-defense studies have been concerned primarily with estimating casualties from a generalized attack upon the United States, based upon varying assumptions of population protection in different geographical areas. These national studies as well as the relatively few local studies have assumed that the enemy would target optimally and that delivery accuracy could be approximated by random error estimates in the study models. This method has usually precluded meaningful comparison of different study results because of differences in the actual ground zeros employed. More important, the results of such studies leave unanswered a number of rather compelling questions: Suppose the weapon is not optimally delivered. Could it not detonate at <u>any</u> point in the city? Should our defenses be keyed to estimates, or perhaps mere conjectures, of the enemy's targeting intentions, the reliability of his weapons, and his delivery accuracy?

The problems posed by ground zero uncertainty are focused more clearly by considering the full range of future potential enemies and their relative achievements in the development and testing of nuclear weapons systems, i.e., the n-th country problem. For example, the center of the business district of a city might be the best target for an attack against population. A shelter posture could be designed to counter effectively a weapon delivered near that point. But, owing to retargeting or error, the weapon could detonate in a densely populated suburban area within the city and kill almost as many people as if there were no shelter posture at all. The shelter system would have bought very little protection, if any.

The shelter strategy proposed in this Study circumvents the uncertainties involved in weapons delivery; fatalities from immediate blast effects and fallout are limited to a given level, no matter where the weapon were detonated in the target area. An obvious way to ensure this outcome would be to allocate the highest level of protection to everyone in the potential target area. Such a posture would limit fatalities to the level expected from a weapon delivered at optimum ground zero. A number of such universal postures were assessed earlier and were found not only to overprotect, but also to entail prohibitive costs. Clearly, a more efficient technique was needed to meet damage-limiting objectives.

A shelter-allocation strategy that is both damage-limiting and least-cost has been developed and is described in this Study. The features which combine to make this strategy unique are its relatively fine-grained local orientation and its consideration of all potential ground zeros in the development of defensive shelter postures. Because of this latter feature, the postures produced by this strategy can make it possible to limit or upper-bound fatalities to a stipulated level, independent of ground zero. A model for executing the strategy will be presented along with specifications for computer adaptation. As will be demonstrated, postures developed by this strategy against a single weapon of a given yield will, at the same cost, also prove highly (if not optimally) effective against weapons of different yields.

II

SHELTER ALLOCATION MODEL

The proposed strategy is to provide a given city or metropolitan area the least-cost shelter posture that will limit fatalities from a given weapon to a stipulated upper level (α)[1] regardless of where the weapon is delivered in the area. The strategy is executed with a unique shelter allocation model. The narrative description of the model below (IIA and B) is followed by a detailed discussion of the inputs and assumptions (IIC) and the computation procedure (IID).

A. DESCRIPTION OF THE MODEL

In preparing for shelter allocation, the model determines the distances from ground zero at which shelters of each strength used in the posture would be required for protection. The regions of interest about ground zero for a single 10 Mt-surface burst,[2] give a choice of blast shelters (100-psi or 35-psi) and fallout shelters (PF = 40 and a 7.3-psi blast rating), are shown in Figure 1, which is a matrix of 1-km^2 elements. Having established these regions of effectiveness, the model evaluates all potential ground zeros[3] and allocates shelters as required to limit fatalities at the stipulated upper level, α.

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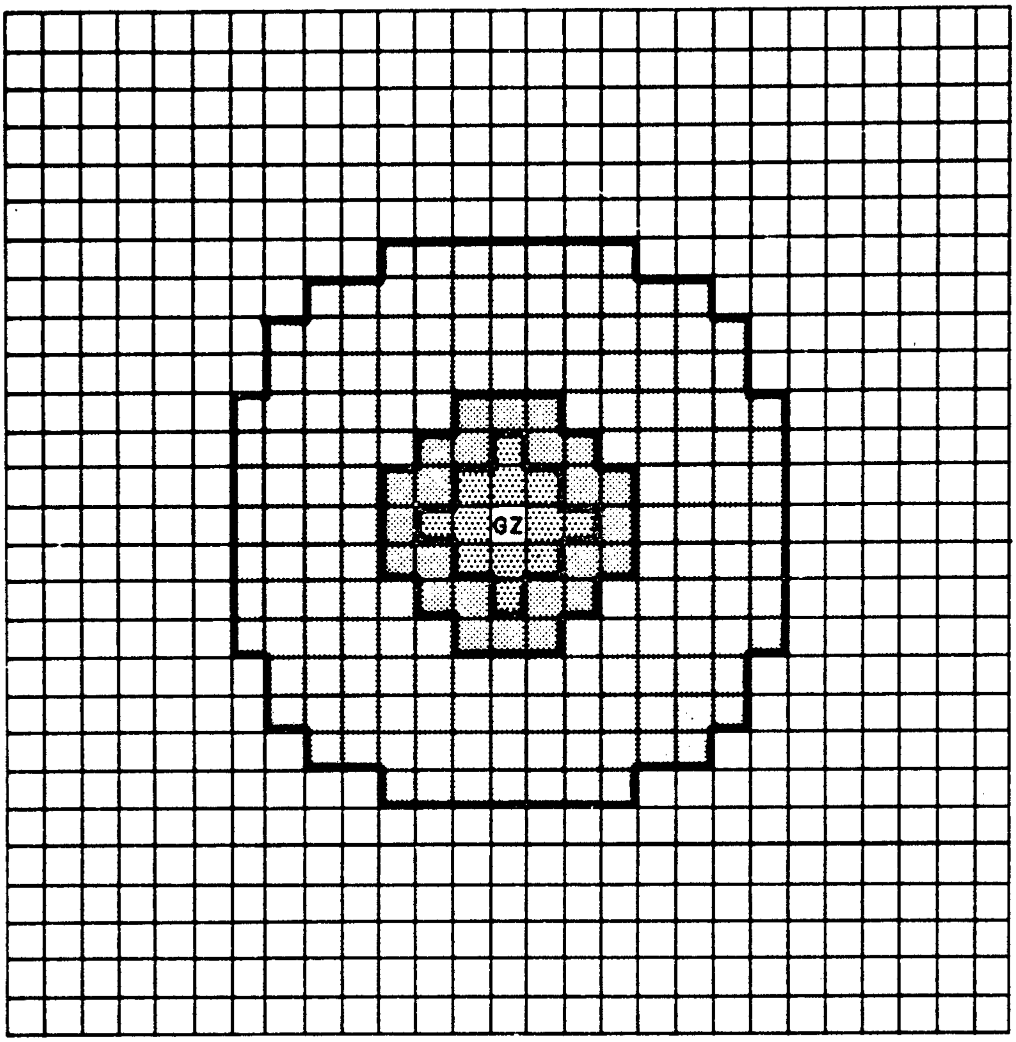
1. A glossary of notation is included as Appendix A.

2. A 0.50 fission ratio was used in calculating the effects of all weapons discussed in this Study.

3. Each element of the population matrix is considered to be a potential ground zero. In effect, the template depicted in Figure 1 is repeatedly shifted, so that the ground-zero square falls in turn on each kilometer-square element of the population matrix, and for each new ground zero the number of blast fatalities is calculated.



Legend:

Region	Overpressure (o)	Adequate Blast/Fallout Protection
= R_o	$o > 100$ psi	None
= R_1	$35 < o \leq 100$ psi	100 psi shelter
= R_2	$7.3 < o \leq 35$ psi	35 psi shelter
= R_3	$o \leq 7.3$ psi	Fallout shelter, PF = 40

GZ = Ground Zero Scale: = 1 km^2

FIGURE 1 A Basis for Determining the Protection Required to Survive at Critical Distances from Ground Zero, 10 MT Surface Burst

(Given a choice of 100 or 35 psi Blast Shelters or fall-out protection in light steel frame bldgs.)

RI-6-65-1

In evaluating each ground zero, the model first determines how many people are within the sure-kill area (R_o in Figure 1). This number is compared with the stipulated upper limit on fatalities to determine the number of fatalities allowable in other regions about ground zero. For example, if the fatality level stipulated for the posture is 50,000 persons and 30,000 were located within the sure-kill region, only 20,000 fatalities are allowable elsewhere. That is, all except 20,000 of the people outside the sure-kill radius must be adequately protected against blast and fallout effects. The next problem is to decide which 20,000 persons will not be protected. Since the objective is to minimize the cost of the required posture, this decision is based on the costs per person protected. The matrix elements with the highest protection costs per person are identified and left unprotected, while the rest of the elements are allocated the shelter required in their particular region about ground zero. In evaluating succeeding ground zeros, all shelters previously allocated are applied as assets, and additional protection is provided only as necessary to hold fatalities to the stipulated level.

After all ground zeros have been evaluated for appropriate blast protection, fallout shelters are allocated to those elements where blast shelters were not previously assigned. The final posture is then costed.

B. SPECIAL FEATURES OF THE MODEL.

The principal features which combine to make this model unique are its local orientation and its deterministic consideration of all potential ground zeros in the development of shelter postures. It also applies a minimum-cost approach to the problem. Each of these characteristics is discussed separately below.

1. Local Orientation

Shelter postures are tailored in this model to the conditions and needs of individual cities or local areas. This local approach

could, of course, be used to develop a national shelter program evaluating the needs of many cities by serial application of the model.

A basic input to the shelter allocation model is a target value matrix in which the population of the target city is broken down according to uniform subdivisions; one-kilometer-square matrix elements are used in the current version of this model. The assumed time of attack determines whether the at-work, at-home or rush-hour population in each grid element will be the basis for shelter assignments.

2. Deterministic Consideration of All Potential Ground Zeros

All grid elements are considered to be potential ground zeros. Each one is separately evaluated in order of target interest. Thus, this is a deterministic as opposed to a probabilistic or "risk"[1] model. Shelter is allocated as necessary to ensure that fatalities from the assumed weapon will not exceed the stipulated level, regardless of where the weapon is delivered on the target city.

3. Minimum-Cost Approach

Three decision rules for minimizing costs are applied in the shelter allocation process.

(1) Shelters of a given strength are not allocated unless essential to maintaining the stipulated survival level.

(2) When additional protection is required, shelters of a given strength are allocated only for those elements in which they are both necessary and effective for protection against the specific ground zero being evaluated.

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1. In a "risk" model, probabilities would be assigned to a number of potential ground zeros and the average or expected damage calculated for each area affected. In contrast, the proposed model deals with the maximum fatalities that could be incurred from a given weapon.

(3) Cost dictates the choice of specific elements to be sheltered. Priority is given to those elements that can be protected at the lowest average cost per required shelter space.

The element-by-element differences in cost per required space are illustrated in Appendix C.

Once shelter of a given strength has been allocated to a population element, it may not be downgraded. However, it may be replaced with a stronger shelter if the process of limiting fatalities for another potential ground zero so dictates.

The shelter-allocation model provides a feasible minimum-cost solution to the problem. Whether it produces the minimum solution will not be argued at this stage of the model's development. In seeking such a solution, linear programming techniques were considered. However, their application was necessarily deferred because of the prohibitive number of constraints now associated with the problem. Available linear programming models, e.g., LP-90, will not accommodate the total constraints involved. Potential means of reducing the constraints include:

(1) reducing the number of grid elements by increasing their size (presently one-kilometer squares);

(2) reducing the total area of the target value matrix, thereby reducing the total number of elements involved;

(3) using fewer sizes and strengths of shelter (perhaps some ideal shelter complex); or

(4) considering the present cost/effectiveness approach as the first step toward the minimum-cost solution and then using the results to determine those areas of the population matrix to which an available linear program could be applied in an attempt to obtain a cheaper solution. The areas appear to be those where a concentration of one level of protection ends and another begins.

The principal difference between a linear programming procedure and that being recommended here is that the former would permit simultaneous consideration of all matrix elements as potential ground zeros. In the present procedure, elements are evaluated one by one, in a

prescribed sequence, crediting as assets all shelters allocated earlier in the sequence.

C. INPUTS, GUIDELINES, AND ASSUMPTIONS[1]

The required inputs to the shelter allocation model are

(1) target value matrix;

(2) the threat;

(3) shelter choices--sizes and strengths;

(4) shelter costs;

(5) the level, α_n, at which fatalities are to be upper-bounded; and

(6) the psi level above which blast shelters would be required for population protection.

Each of these is discussed separately below.

A target value (population) matrix is input for the target city to be protected. This matrix was described earlier on pages 5 and 6.

The threat to be countered by the shelter posture is also an input. This includes the yield of the weapon and height of burst. Wind direction and speed are considered externally in determining the level of fallout protection required.

The shelter strengths and sizes available for allocation and their respective costs are also inputs to the model. See Appendix C for examples and cost sources.

Shelter costs: The total population, p_{ij}, of a grid element (identified in aggregate only) is the basic decision unit affecting cost. Each p_{ij} will be provided a uniform level of protection, i.e., shelters of the same psi rating, or the same fallout protection factor, for everyone in the element.

The level (α_n) at which fatalities are to be upperbounded is also an input. A series of postures can be developed and costed

1. Appendix A is a glossary of all notation used here and in Section IID. A set of specifications for computer adaptation of the model is provided in Appendix B.

based on alternative α_n levels, thus providing discrete points for the construction of cost/effectiveness curves. The range of feasible α_n levels is determined by the threat to be countered and the alternative shelter strengths available for the posture.

(1) The minimum level at which fatalities can be upper-bounded (α_1) is the number of people that would be killed by blast effects from the stipulated weapon if the strongest shelter available for the posture (s_1) were provided universally. That is, even if s_1 shelters were allocated to everyone, the assumed weapon could kill as many as α_1 people from blast effects, depending upon its actual ground zero within the city.

(2) The maximum level of fatalities for which at least some s_1 shelter would be required (α_m) is one less fatality than the upper limit protected by the next strongest shelter (s_2). For example, if fatalities could be limited to 50,000 with s_2 blast shelters (or with fallout shelters if blast shelters of only one strength are being allocated), the maximum α requiring allocation of any s_1 shelter is 49,999. If any higher α were stipulated, the model would not allocate any s_1 shelter, as it would not be required. (The model will not allocate a stronger shelter if a less expensive shelter of lower strength will provide an equivalent number of survivors. Likewise, it will not allocate any blast shelters if fallout shelters will ensure the stipulated number of survivors.)

The fatality levels corresponding to α_1 and α_m need not be specified in advance, as their values will be computed as a preliminary step in the shelter allocation procedure itself.

The minimum psi level for which blast shelters would be required for population protection is also an input and can be varied.

D. COMPUTATION PROCEDURE

The first three steps in the computation are in preparation for the shelter allocations; the fourth and fifth are the allocation procedure, and the sixth is the costing procedure.

Step 1: Establish Shelter Effectiveness Radii

In preparing for shelter allocation, it is necessary to determine the distances from ground zero at which a shelter of specified strength k will be effective. The distance to be calculated is r_k, the outer limit of the region R_k within which a shelter of a given strength in

the posture will protect and a weaker shelter in the posture will not. Distance r_k is determined from overpressure-versus-distance formulas,[1] properly scaled for weapon yield and height of burst. Figure 1 depicts for a 10-Mt surface burst, the region of effectiveness for each of three shelter strengths: 100- and 35-psi blast shelters, and fallout shelters.

Step 2: Determine α_1, the Minimum Level at Which Fatalities Can Be Upper Bounded

P_o is the population in the unprotectable region R_o, with outer radius r_o, about a given ground zero. In this region the overpressure from the assumed weapon will exceed the psi rating of even the strongest shelter. R_o contains all matrix elements located at distances, d_{ij}, from ground zero that are less than or equal to r_o. The distance, d_{ij}, of an element in the i-th row, j-th column from a ground zero in the m-th row, n-th column is determined by the following formula:

$$d_{ij} = \sqrt{(i-m)^2 + (j-n)^2}$$

If $d_{ij} \le r_o$, the element i,j is included in R_o, and

$$P_o = \sum_{R_o} p_{ij}.$$

Calculate P_o for each grid element, considering that each is a potential ground zero.[2] The highest P_o calculated is α_1, the minimum level at which fatalities can be upper-bounded with the shelter choices at hand.

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1. Based on data provided in Figure 3.66 of S. Glasstone (Ed.), The Effects of Nuclear Weapons, U.S. Department of Defense (U.S. Atomic Energy Commission: Washington, D. C., April 1962), p. 135.

2. As will be described later, the resultant P_o values also provide the basis for ordering elements for evaluation as potential ground zeros in the shelter allocation process.

Step 3: Determine α_m, the Highest Fatality Level that Would Require Any s_1 Shelter Allocation

P_1 is the total population in regions R_o and R_1 about a given ground zero.

$$P_1 = \sum_{R_o} p_{ij} + \sum_{R_1} p_{ij} \quad .$$

The second strongest shelter under consideration (s_2) will not protect within R_1 (bounded by radius r_1), but will protect outside r_1. Therefore, to bound fatalities at P_1 would require no s_1 shelters. The populations of all elements with $d_{ij} \leq r_1$ are included in P_1.

Calculate P_1 for each grid element considering that each is a potential ground zero. The highest P_1 calculated, P_{1max}, is the minimum level at which fatalities can be upper bounded with s_2 shelters. Thus,

$$P_{1max} - 1 = \alpha_m \quad ,$$

the highest fatality level that would require allocation of any s_1 shelter.

Step 4: Determine Shelter Requirements and Allocate Shelter

Array the blast-shelter choices in order of psi rating, highest to lowest. Classify the strongest shelter s_1, the next strongest s_2, etc. Allocate shelters one strength category at a time, in the order s_k ($k = 1, 2, 3, \ldots$).[1] To allocate s_k shelter:

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1. An alternative for this step is discussed at the end of this Section. See page 14.

Step 4a: Array the matrix elements from highest to lowest according to the numbers of persons, V_{mn}, vulnerable even with s_k shelters, to determine the order in which they are to be evaluated as potential ground zeros.[1]

For the strongest shelter, s_1,

$$V_{mn} = P_o \quad .$$

The P_o values were calculated in Step 2 above.

For other shelter strengths, s_k (k = 2, 3, ...),

$$V_{mn} = P_o + (U_1 + U_2 + \ldots + U_{k-1}); \;\; ;$$

where U_k (k = 1, 2, 3, ...) is the total population in those elements of R_k which were not allocated s_k shelters.

Step 4b: Evaluate each element a_{mn} as a potential ground zero and allocate s_k shelter as follows:

Calculate f_k, the allowable fatalities in R_k, where

$$f_k = \alpha_n - V_{mn}$$

(α_n is an input, as described earlier in this Section on pages 7 and 8).

Calculate U_k where

$$U_k = \sum_{R_k} u_{ij} \quad ;$$

and the u_{ij} are the populations in elements i,j which have not already received s_k or stronger shelter.

1. Ground zeros could be evaluated in any conceivable sequence and still accomplish the objectives of the proposed strategy. Simultaneous consideration of all ground zeros, using a linear programming approach, might provide a somewhat lower-cost solution as discussed in IIB3.

If $U_k \leq f_k$, no additional s_k shelter is required for this ground zero.

If $U_k > f_k$, some s_k shelter is required. Calculate the average cost per required shelter space, c_{ijk}, highest to lowest. This array will be used to determine which elements are to be left unsheltered in R_k at this point in the allocation process.

Starting with the unprotected element having the highest c_{ijk} in R_k, select to leave unprotected each element down the array until either all u_{ij}'s have been selected and the sum $\leq f_k$ <u>or</u> the sum of the u_{ij}'s equals or just exceeds f_k. If this latter sum just exceeds f_k, reduce it by the last u_{ij} added. The u_{ij} elements remaining in the sum are left unsheltered and all others in R_k are assigned s_k shelters in the numbers and sizes required.

<u>Step 4c</u>: All elements other than the first are evaluated in sequence, highest to lowest V_{mn}. Repeat Step 4b above.

<u>Step 4d</u>: Repeat Steps 4a through 4c for each s_k shelter until all choices (k = 1, 2, 3, ...) have been considered and allocated as necessary.

Step 5: <u>Allocate Fallout Shelters</u>

When all shelter choices s_1, s_2, ..., s_n have been allocated in accordance with the above procedure, the blast shelter portion of the posture is completed. The next step is to allocate adequate fallout shelter to all the p_{ij}'s which were not assigned special blast protection.[1]

Step 6: <u>Costing</u>

Cost this posture using available cost factors for the shelter choices (strengths and sizes) allocated. The most economical combination of shelter sizes that will protect a given p_{ij} with the

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1. The required level of fallout protection, e.g., PF $\geq$ 40, for the given threat, is determined by a separate IDA computer routine called FALDIK.

assigned shelter strength, s_k, is always used as the basis for blast shelter costing. In the present model, required fallout shelter protection is costed by summing the unsheltered population at the end of Step 3 above, and then applying a single, average cost per person for fallout shelter.[1] The sum of the costs for blast shelters and fallout shelters equals the total cost of the posture required to limit fatalities to α_n for the given threat. Since blast shelters provide adequate fallout protection, the total population has been protected against fallout. Therefore, the fatalities bounded by α are attributed to blast effects.

E. ALTERNATIVE ALLOCATION PROCEDURE

Step 4 in the present version of the model requires that shelters be allocated one strength at a time, starting with the strongest. This procedure shortens the allocation process because the stronger shelters apply as assets when the weaker shelters are being allocated. However, all shelter strengths could be considered simultaneously within the regions where they are both effective and necessary with respect to each potential ground zero. Once this was done for the first ground zero, the problem for succeeding ground zeros would be to determine when and where existing weaker shelters should be upgraded as a lower cost alternative to allocating more shelters of higher strength to previously unsheltered grid elements. The upgrading problem is avoided in the present shelter allocation procedure.

A situation is conceivable in which this alternative would be preferred. In assigning relative priorities to determine which grid elements will be sheltered, it is possible that the <u>cost per person</u> of allocating stronger shelter to one grid element would be found to be lower--due to the applicability of more economical

1. See Appendix C for cost data applied in pilot studies.

shelter capacities--than the cost of allocating shelter to a less densely populated element, where a lower strength would provide the required protection. This problem should be considered in further development of the shelter allocation model.

III

DAMAGE-LIMITING SHELTER POSTURES FOR HOUSTON: A PILOT STUDY

Twenty-five alternative shelter postures were developed and costed for Houston, Texas, to demonstrate the cost/effectiveness of a damage-limiting strategy implemented through the shelter-allocation model described in Section II. The specifications for these postures are listed below.

(1) Houston 1960 at-home population (1,225,898)

(2) A single 10-Mt surface burst

(3) Blast-shelter protection is assumed required inside the 7.3-psi radius with respect to a given ground zero

(4) Light steel-frame fallout shelters are assumed to provide blast protection against overpressures not greater than 7.3 psi.[1]

Alternative shelter configurations[2] and fatality levels considered in this exercise are given in Table 1.

A. SHELTER ALLOCATIONS

Figure 2 shows the 1960 at-home population of Houston, Texas, allocated to the 65 x 65 matrix of one-kilometer-square elements used in these studies.[3]

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1. The overpressure at which the kill probability is 0.5 for light steel-frame buildings, according to Dikewood's blast mortality curves. L. Wayne Davis et al., Prediction of Urban Casualties from the Immediate Effects of a Nuclear Attack (U) CONFIDENTIAL, Dikewood Corporation, Contract No. OCD-OS-62-203 (Albuquerque: April 1963).

2. A listing of the various shelters considered available for these postures and their respective costs is provided in Appendix C.

3. Note that the entire 65 x 65 matrix is not shown in any of these Figures. Some unpopulated rows at the top and bottom have been omitted.

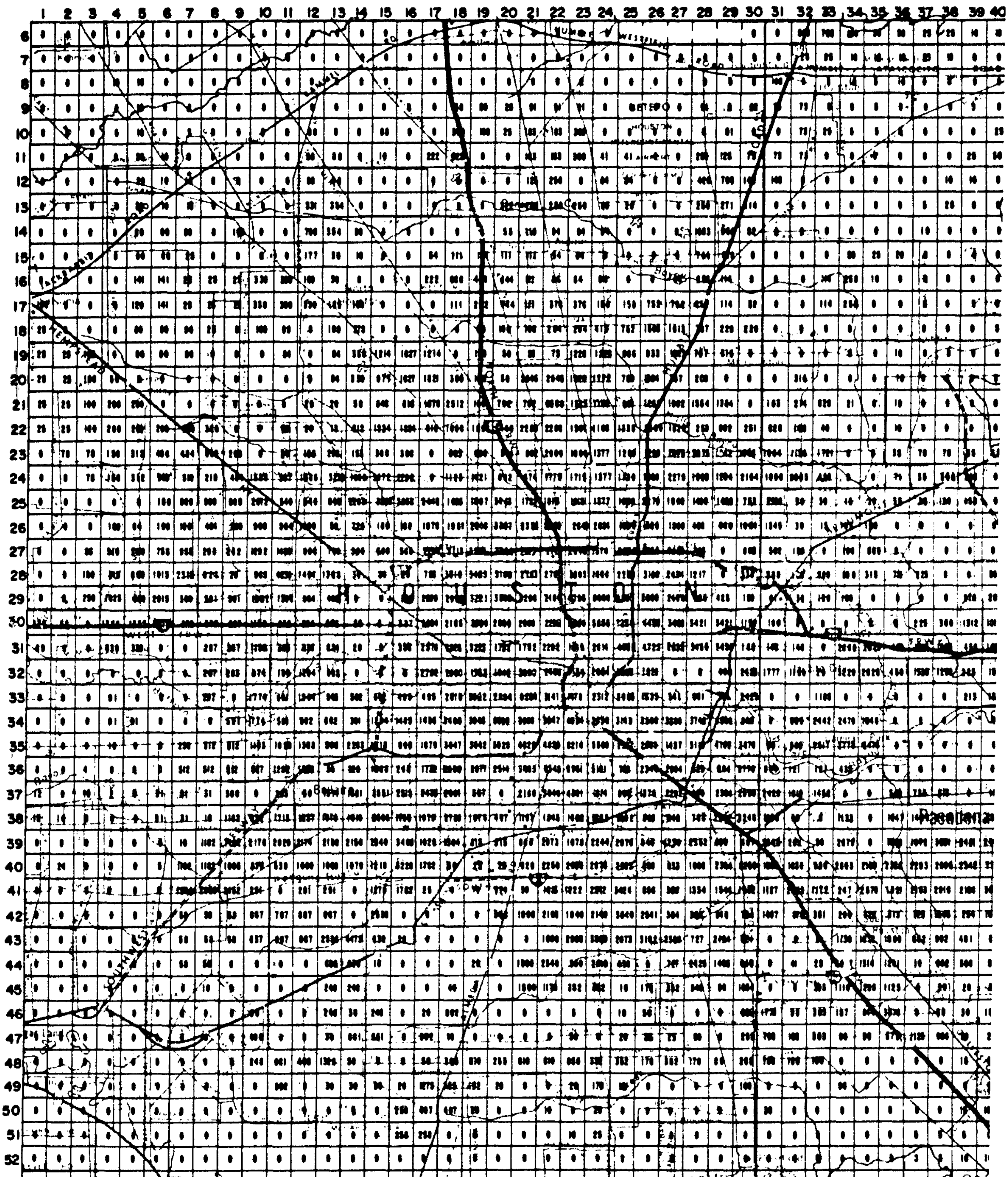
Table 1

SHELTER POSTURES CONSIDERED FOR HOUSTON

(Single 10-Mt Surface Burst, At-Home Population)

Maximum Fatality Level (α)		Shelter Posture Evaluated to Achieve α[a,b]						
Percent of Population	Number of Fatalities	300 psi	100 psi	35 psi	300/100/ 35 psi	300/100 psi	100/35 psi	Fallout (7.3 psi
2.2[c]	26,955	x			x(3)	x		
4.0	49,036	x			x	x		
5.04[d]	61,774	x	x				x(4)	
10.0	122,590	x	x				x	
10.68[e]	130,965	x	x	x(5)				
20.0	245,180	x	x	x(6)				
30.0	368,769	x	x	x				
35.0	429,065	x	x	x				
36.67	449,537							x

a. PF > 40 fallout shelters with a blast rating of 7.3 psi are allocated to all populations that do not receive blast shelters.
b. Numbers in parentheses correspond to Figures depicting these postures.
c. α_1, the minimum, for 300-psi shelters.
d. α_1, the minimum, for 100-psi shelters.
e. α_1, the minimum, for 35-psi shelters.



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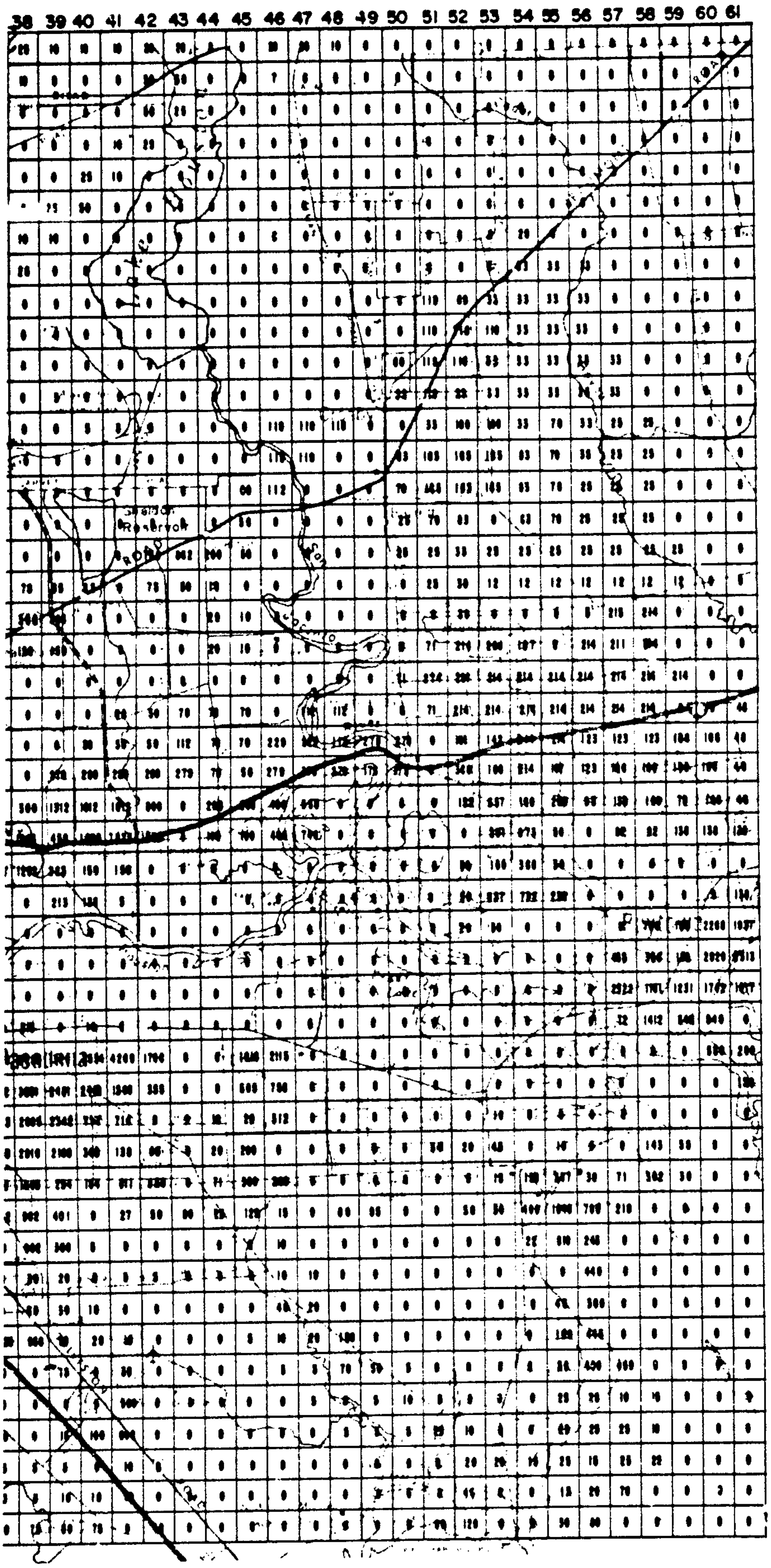


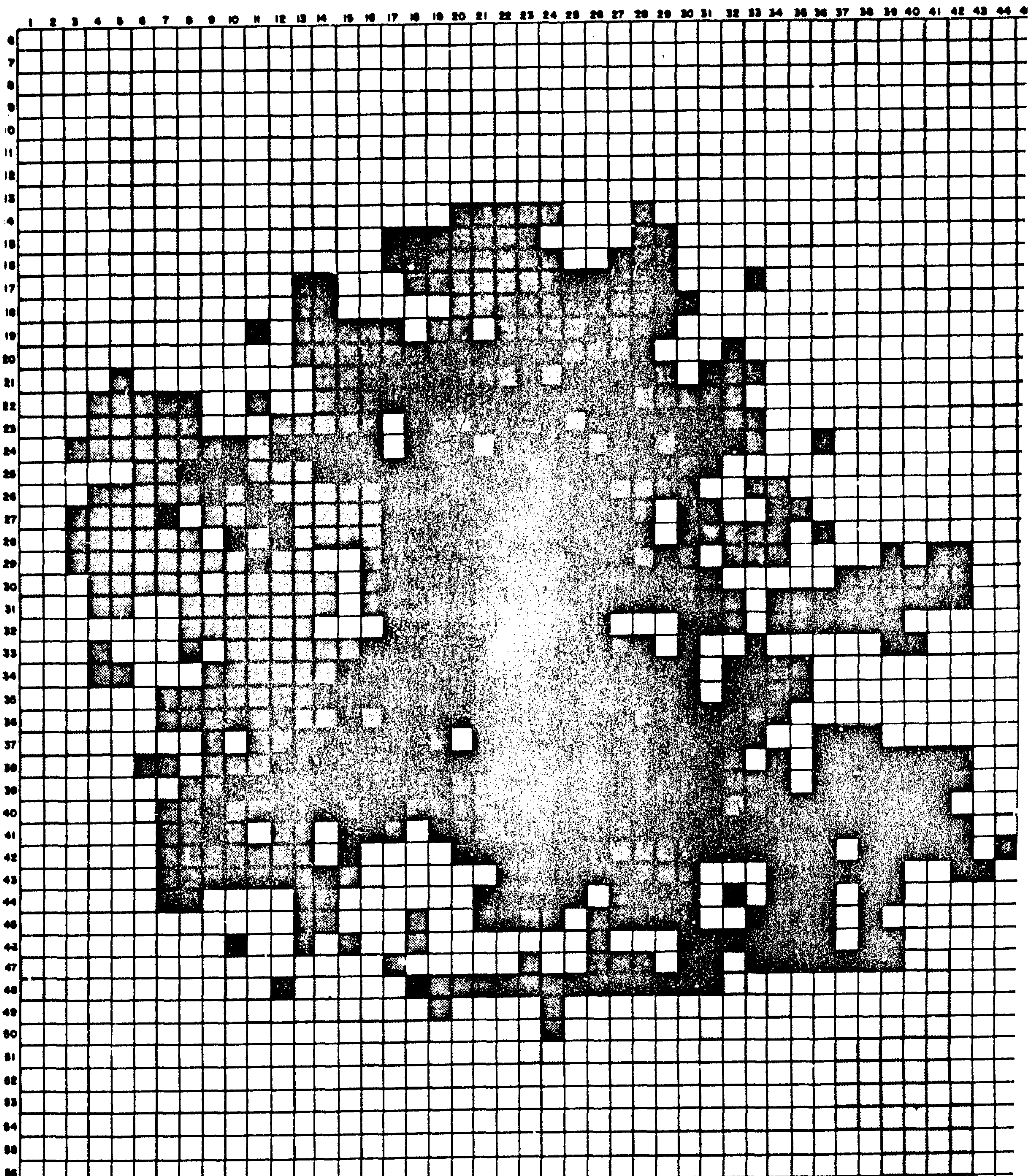
**FIGURE 2 Houston Target Value (Popula
Matrix**

$\boxed{428}$ = Persons per square kilomete

Shelter postures showing the strength of the shelter allocated to each grid element are shown in Figure 3 through 6 for four of the more interesting postures listed in Table 1. The population detail of Figure 2 is not shown in these Figures, but each matrix element can be identified by its column and row coordinates at the top and left of each Figure. The first three of these postures provide the highest survival levels attainable with three of the different shelter configurations studied: 300/100/35 psi (Figure 3), 100/35 psi (Figure 4) and 35 psi (Figure 5). Figure 6 illustrates a 35-psi posture designed (under assumed budgetary constraints) for only 80 percent survival. This posture, designed for a survival level lower than the highest attainable, demonstrates the capability of the shelter allocation model to accommodate budgetary constraints. Compare this posture with the posture shown in Figure 5, which was designed to achieve the highest survival level attainable with 35-psi shelters, i.e., 89 percent.

B. COST/EFFECTIVENESS

The pilot studies, based on cost data described in Appendix B, revealed that the 35- and 100-psi postures under the same design conditions have substantially equal cost/effectiveness ratios at the 65 to 89 percent survival levels. In comparison to a 35-psi posture, the 100-psi posture required fewer spaces for the same level of effectiveness because it offers a higher survival rate per shelter space. This increased effectiveness offsets the higher cost of the 100-psi shelters. This relationship also held for the mixed-shelter cases, i.e., the 100-psi and 300/100-psi postures proved to be as efficient as the 100/35-psi and the 300/100/35-psi postures respectively. This is a significant finding because, as will be shown later (Section III C) 100-psi postures designed for a single 10-Mt attack prove far more efficient against higher-yield weapons than comparable 35-psi postures.


1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44
6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58

A

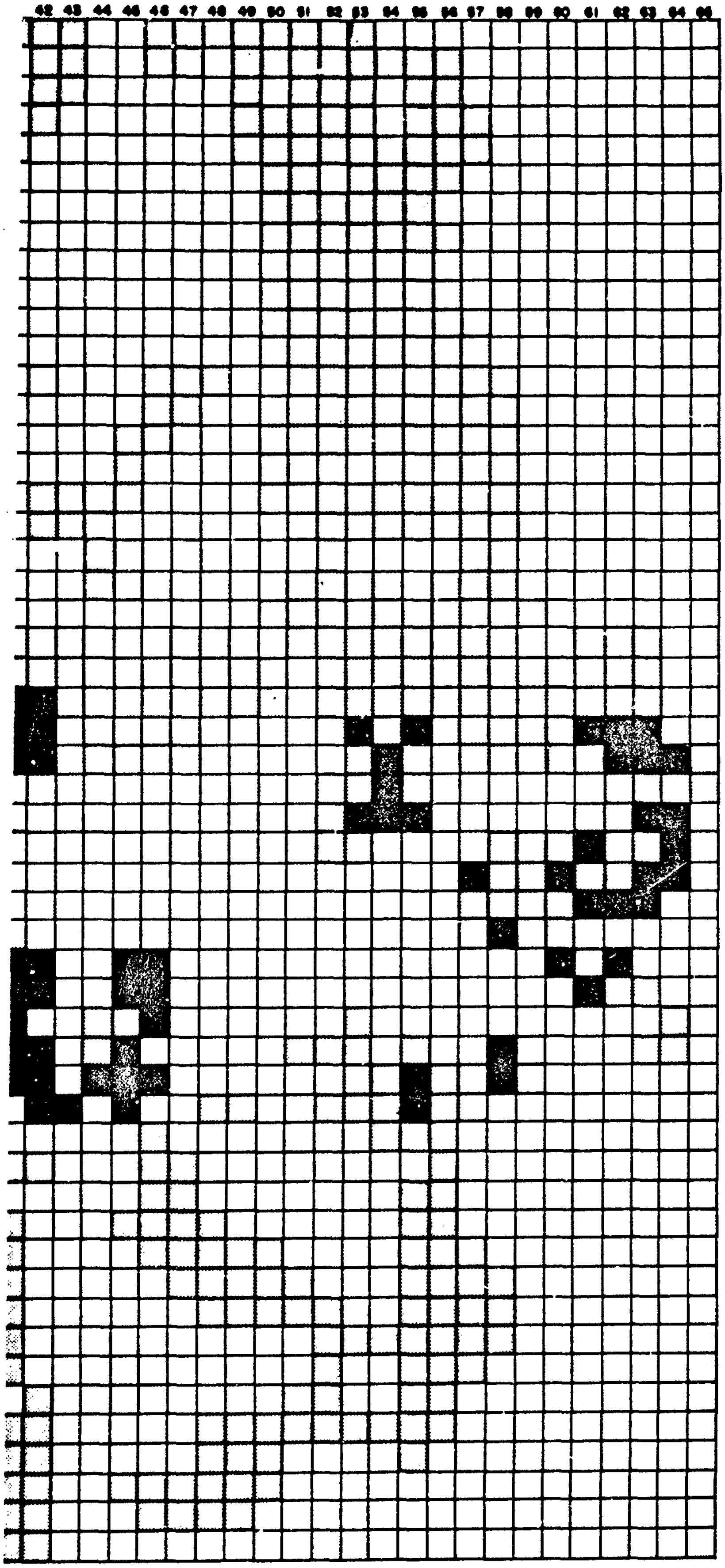
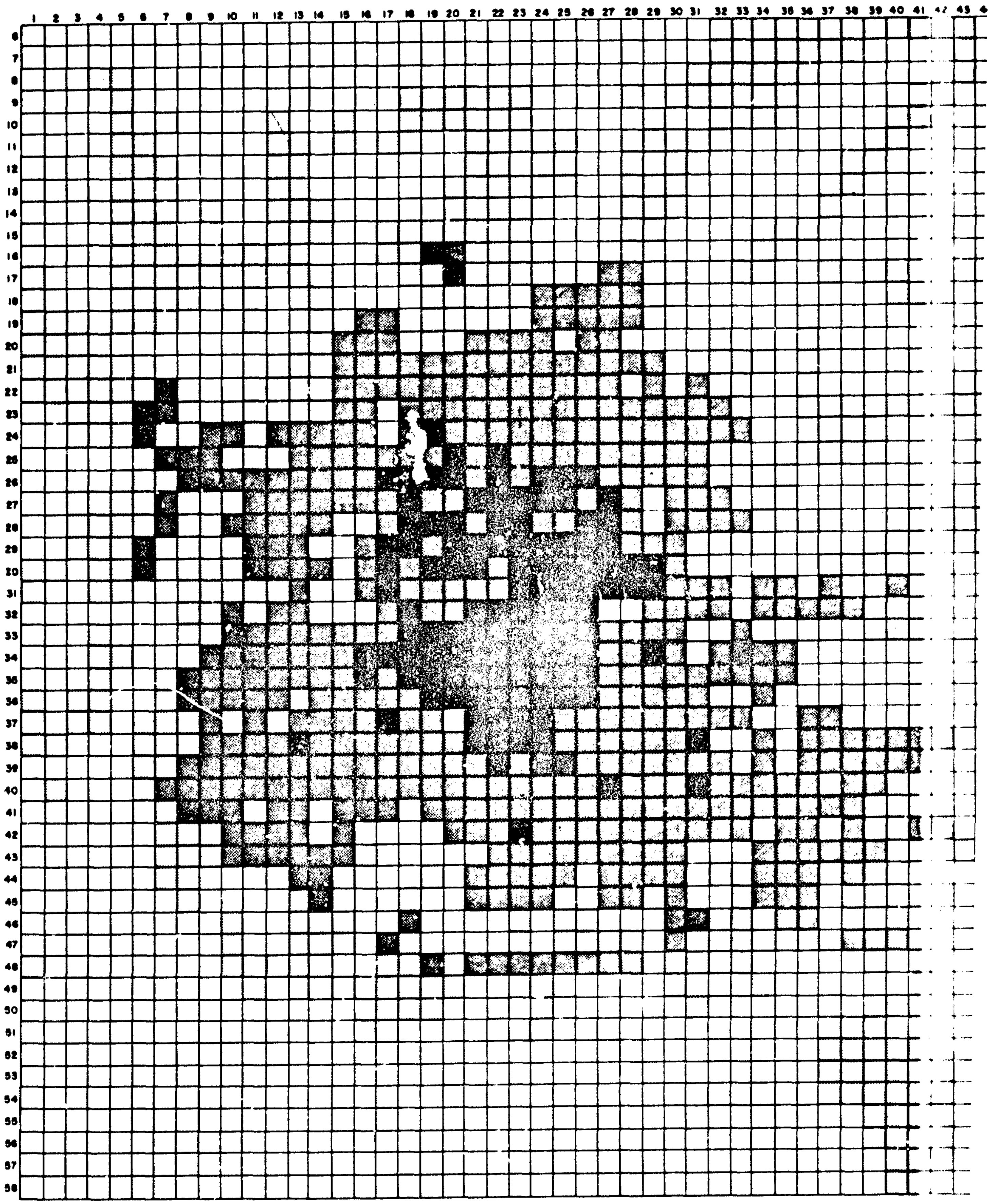


FIGURE 3 Shelter Posture: 300, 100, and 3
Blast Shelters; Maximum Allowabl
Fatalities: 2.2 percent (One 10-
Surface Burst against Houston At-
Population)

300 psi shelters
100 psi shelters
35 psi shelters
Fallout shelte
PF ≥ 40
Unpopulated


1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43
6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58

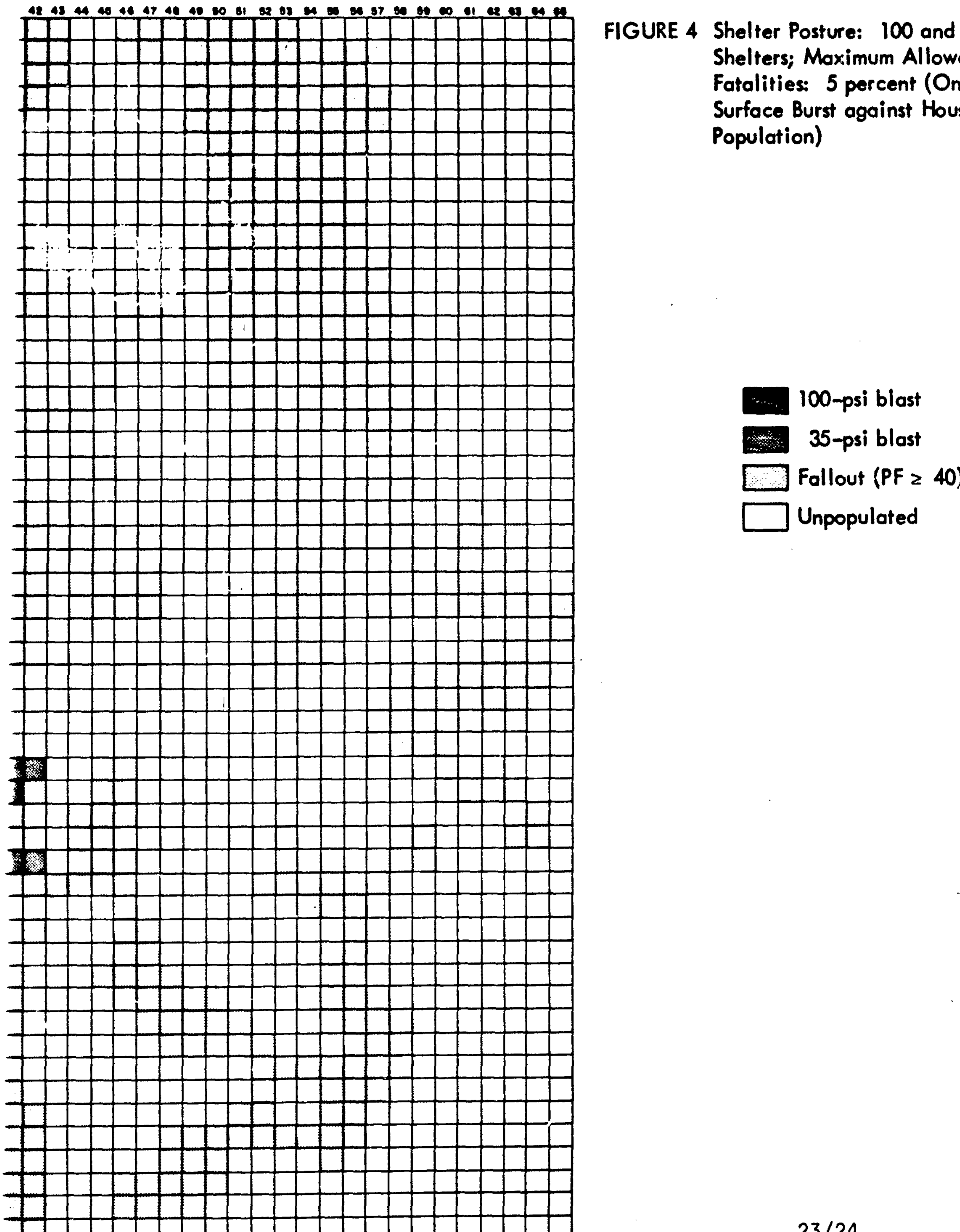
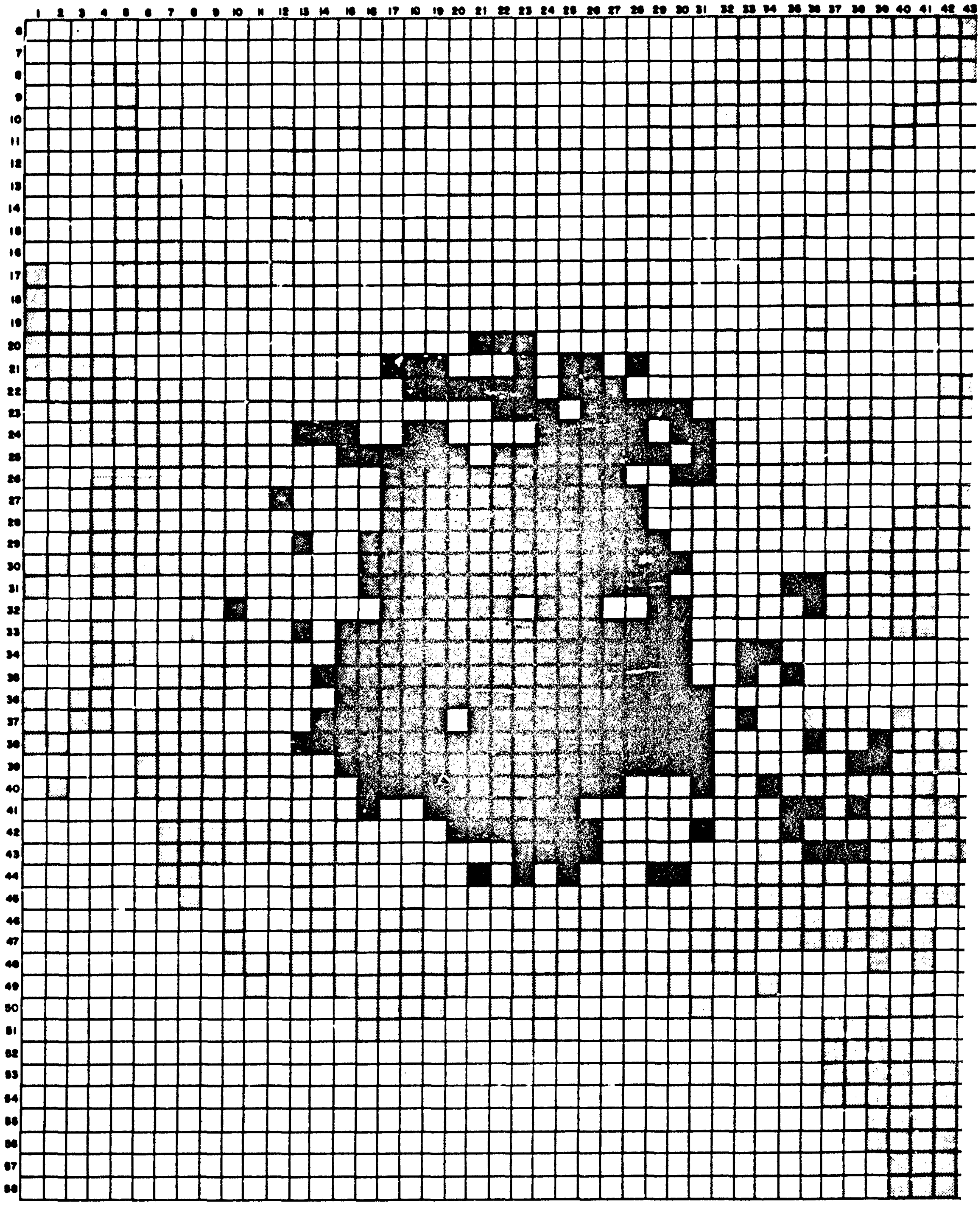


FIGURE 4 Shelter Posture: 100 and 35-psi Bl
Shelters; Maximum Allowable
Fatalities: 5 percent (One 10-Mt
Surface Burst against Houston At-I
Population)



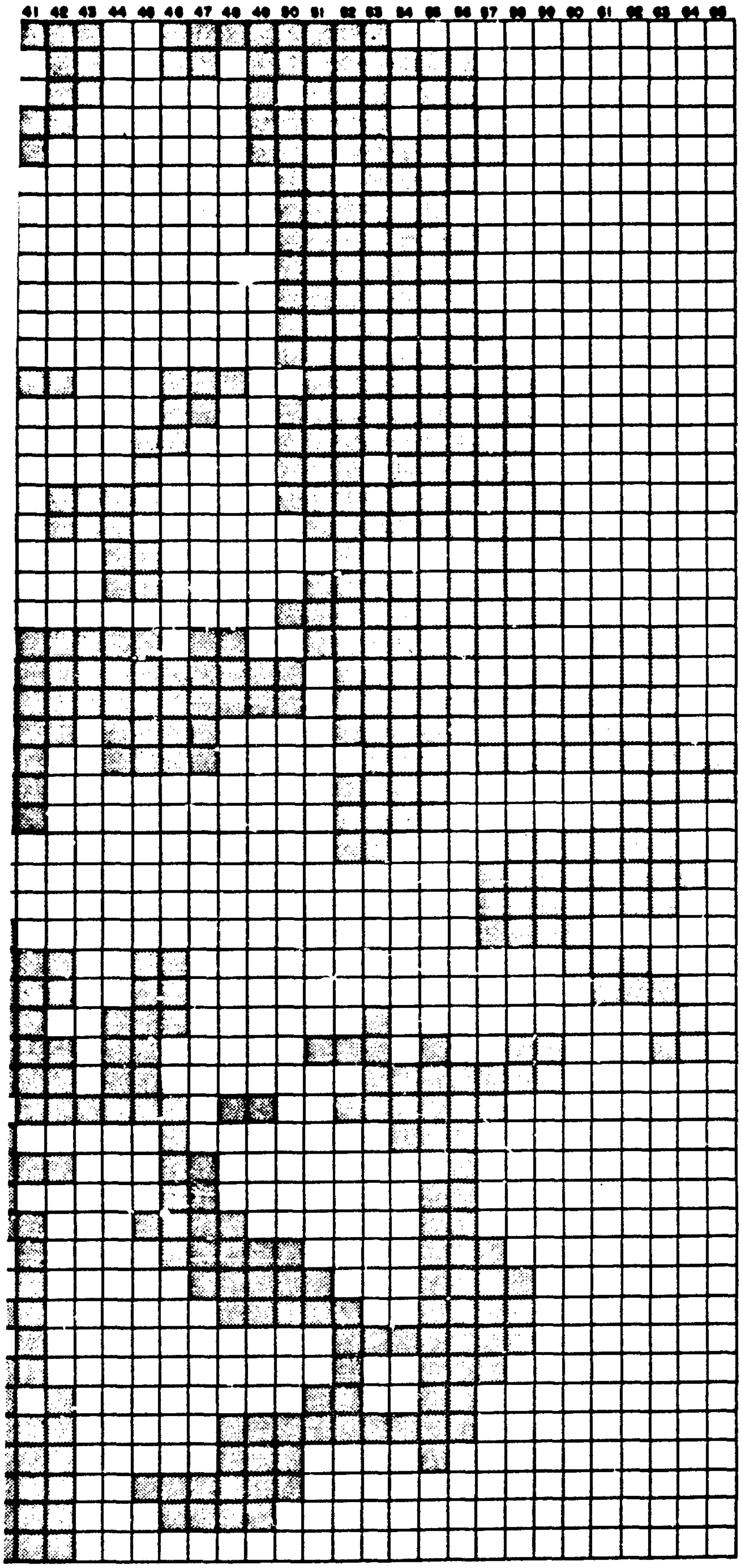
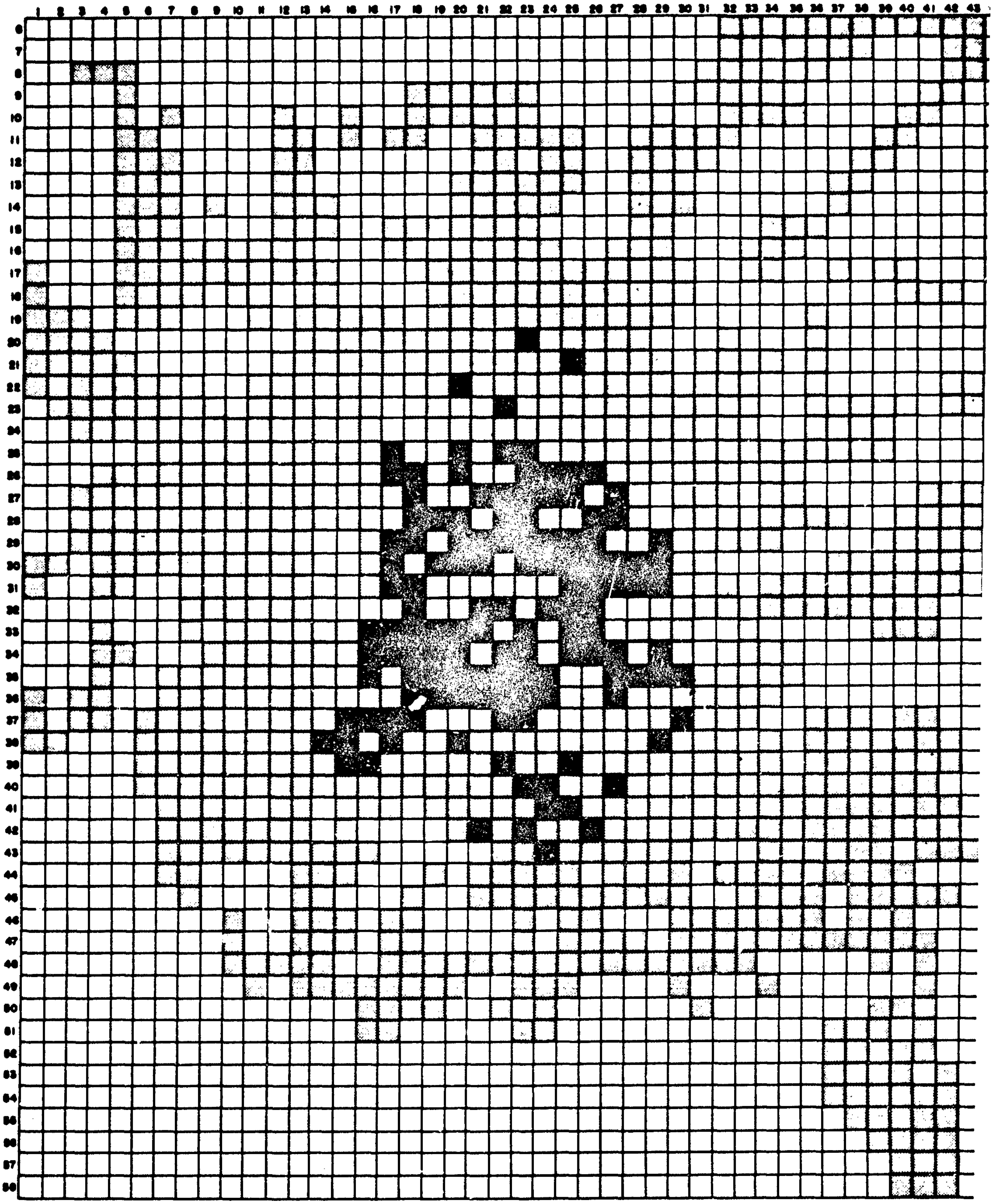


FIGURE 5 Shelter Posture: 35–psi Blast She
Maximum Allowable Fatalities:
percent (One 10–Mt Surface Burs
against Houston At–Home Popula

35–psi blast

Fallout (PF ≥ 40)

Unpopulated



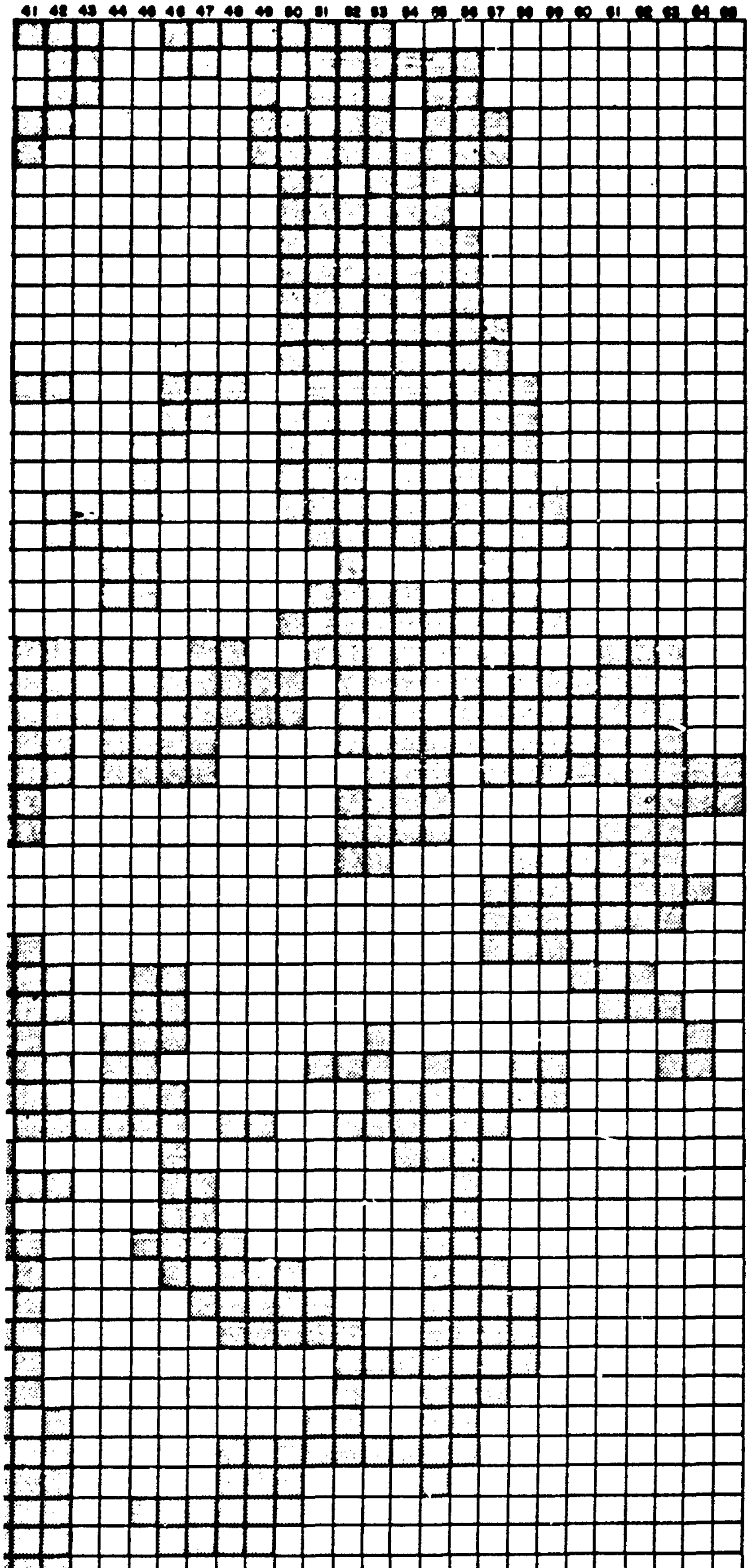


FIGURE 6 Shelter Posture: 35-psi Blast She
Maximum Allowable Fatalities:
percent (One 10-Mt Surface Bur
against Houston At-Home Popula

35-psi blast

Fallout (PF ≥ 40)

Unpopulated

The 35-psi configuration, which shows no special utility at the 65 to 89 percent survival levels, drops out of competition above the 89 percent level, the highest attainable when restricted to 35-psi blast protection. At the 90 to 95 percent levels, the 100-psi postures are more efficient than the 300- or 300/100-psi alternatives. The highest survival level attainable with 100-psi shelters is 95 percent under the stated attack conditions.

Mixed postures comprising some 300-psi shelters are the most efficient at survival levels attainable above 95 percent. For example, at the 98 percent level -- the highest that can be guaranteed with 300-psi shelters -- the required 300/100-psi mix costs only $548 million as compared to $828 million for a posture in which the choice of blast shelter is limited to the 300-psi design. The damage-limiting mix compares even more favorably with the universal 300-psi posture, which costs twice as much ($1,014 million) but which could not guarantee more than 98 percent minimum survival under the same attack conditions.

Figure 7 depicts the cost and effectiveness of the most efficient postures developed in the pilot study.[1] Postures are included for a number of different survival levels ranging from 65 to 98 percent.[2] The cost/effectiveness relationship for each of the following universal postures (uniform protection for all) is also shown for comparison:

(1) 7.3-psi, PF = 40 fallout shelters (63% minimum survival)
(2) 35-psi blast shelters (89% minimum survival)
(3) 100-psi blast shelters (95% minimum survival)
(4) 300-psi blast shelters (98% minimum survival)

1. The numbers and costs of blast and fallout shelter spaces comprising each of these postures are provided in Appendix D.

2. It is important to recall that, as described in Section II, people who do not receive blast shelter protection under the damage-limiting allocation procedure are allocated fallout shelter protection (7.3 psi, PF = 40) at substantially lower cost per space required.

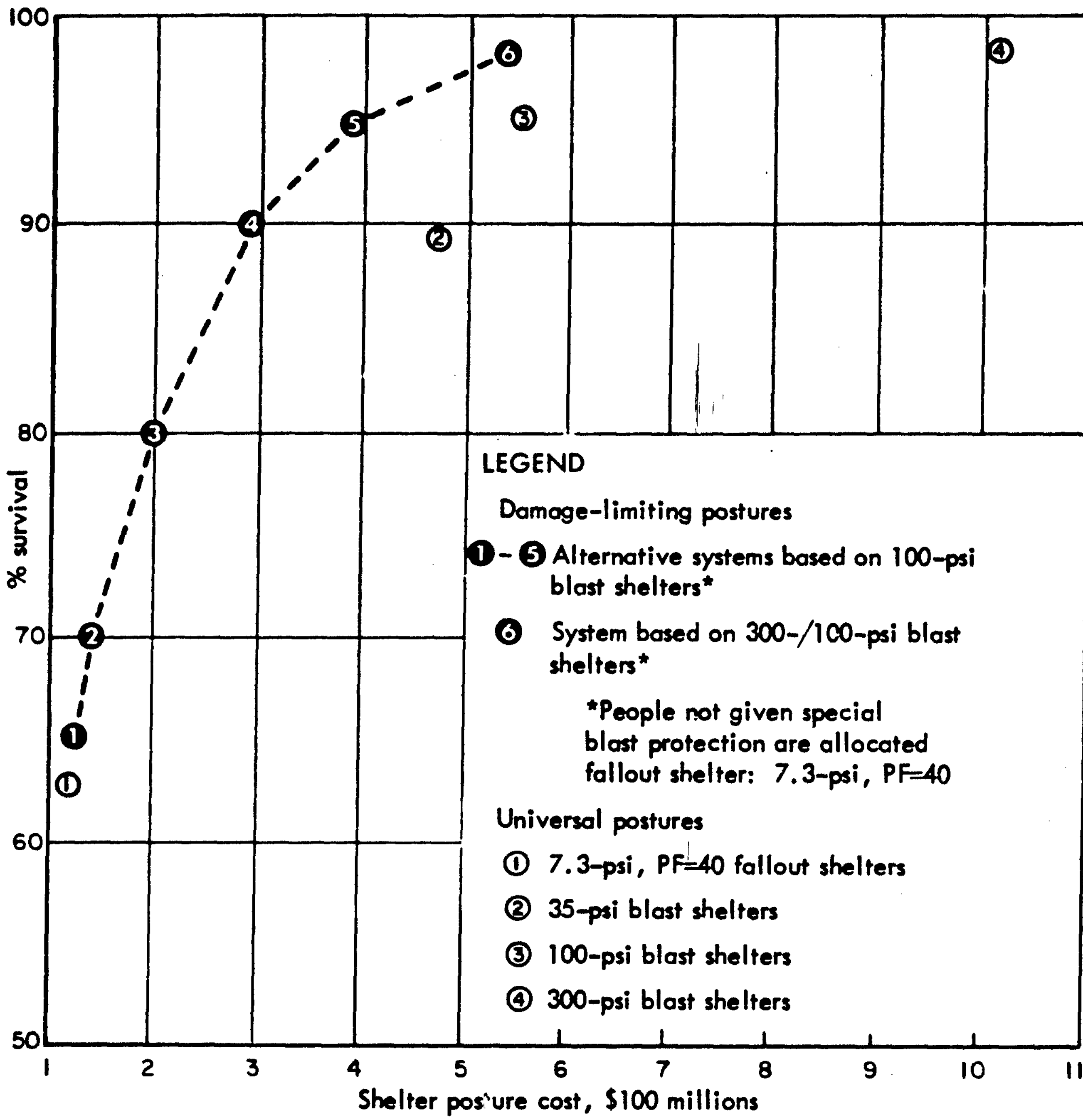


FIGURE 7 Cost and Effectiveness of Alternative Shelter Postures (single 10-MT surface burst against the Houston at-home population)

As indicated above, blast shelters are not required for survival levels less than or equal to 63 percent. Fallout shelters alone, allocated in the grid elements where the populations reside and fully occupied,[1] would enable 63 percent survival. Although not shown in Figure 7, only 18 percent of the Houston population would survive if no special shelter were provided and people remained in their residences.

Average and marginal costs per survivor for each shelter configuration are readily obtainable from the model output.

C. YIELD SENSITIVITY

Two alternative attacks were used to test the yield sensitivity of several of the postures developed for this pilot study. Designed to counter a single 10-Mt threat to the Houston at-home population, the postures were tested against single 3-Mt and 100-Mt weapons, each a surface burst at its optimum ground zero. The results for the best 10-Mt postures -- those which were determined to be most efficient at each survival level studied (Figure 7) -- are shown in Figure 8.

As reported earlier, the efficiency of alternative postures comprising 35-psi and 100-psi blast shelters was determined to be substantially equivalent against the design threat of 10 Mt. However, the efficiency of 35-psi postures is significantly below that of the 100-psi postures when subjected to the higher yield (100-Mt) attack. The yield sensitivity of 35- and 100-psi shelter designs, having comparable 10-Mt survival levels at each of four budget levels, is reflected in Table 2.

---

1. Occupancy percentages can be varied in applying the model.

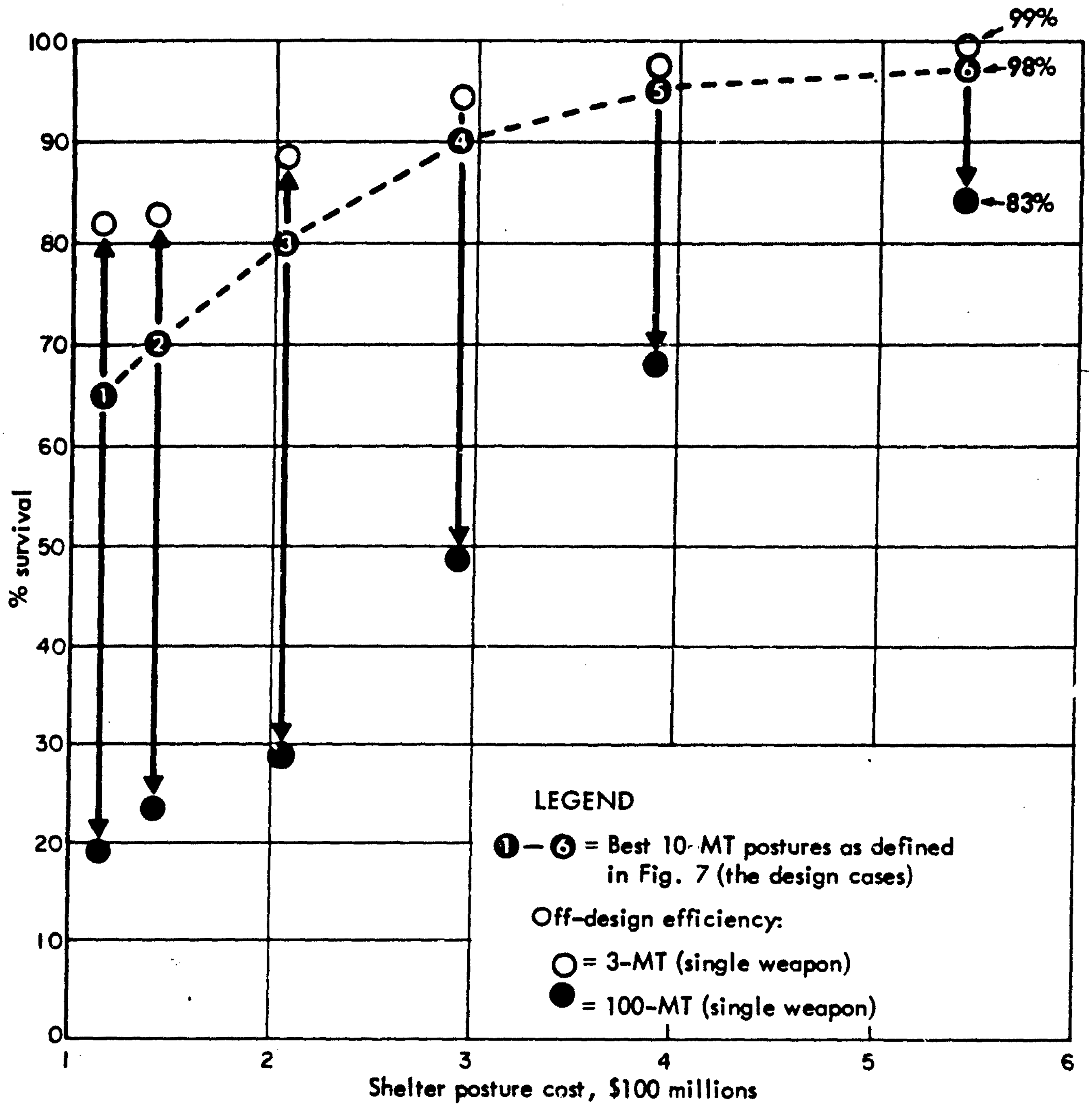


FIGURE 8 Yield Sensitivity of Postures Designed to Counter a Single 10-MT Attack

Table 2

YIELD SENSITIVITY OF COMPARABLE 35-PSI AND 100-PSI BLAST POSTURES

(Designed to Counter a Single 10-Mt Surface Burst, Houston At-Home Population)

Budget Level millions of $	Blast Shelter Utilized in Posture[a]	Minimum Survival Level, % On-Design (10-Mt)	Off-Design 3-Mt	Off-Design 100-Mt
290	35-psi	89	93	38
	100-psi	89	93	47
200	35-psi	80	88	22
	100-psi	80	89	29
145	35-psi	70	83	18
	100-psi	70	83	23
120	35-psi	65	82	16
	100-psi	65	82	19

a. People for whom blast shelter is not provided are allocated fallout shelter protection: 7.3 psi, PF=40.

IV

CONCLUSIONS AND RECOMMENDATIONS

The pilot study reported in Section III confirms that shelter postures developed under the damage-limiting strategy proposed here can make it possible to limit fatalities to a stipulated level regardless of where the weapon may be delivered within a target city. This study also established that by allocating shelters according to the model presented, fatalities can be limited to the level expected if shelters of the highest psi rating under consideration were provided universally (at much greater cost) and if the weapon were detonated at the enemy's best aimpoint.

It is recommended that the model be used to test the sensitivity of the results to all input criteria and parameters which significantly affect shelter requirements and costs. Initial plans are that the model will be used to study the sensitivity of the results to the size of the matrix elements (now one-kilometer square). Alternatives include the use of two-kilometer-square elements, which would reduce the total number of matrix cells from 4,225 to 1,024; or the use of census tracts, which are not uniform in size or shape. The geographic center of each tract can be used as the basis for measuring weapon effects over the whole tract area.

The model also will be used to develop protective postures for different population modes: at-home, at-work or rush-hour. These postures will then be tested against alternative times of attack: day, night or rush hour, as well as alternative yields and numbers of weapons. The results will delineate those postures with the lowest cost/effectiveness ratio over a range of circumstances.

Some possible avenues of research for further development of the model itself[1] are as follows:

1. Also see discussion in Section IIE.

(1) Incorporate a probability of kill (P_k) function for use in estimating fatalities among people occupying different strength shelters. The P_k would vary according to the specific overpressure level applied and should, of course, be consistent with the design specifications for the shelter. A cookie-cut criteri is applied in the present model, i.e., all people live if the overpressure does not exceed the psi rating of their shelter; al people die if it does.

(2) Allow for divisibility or combination of grid elements in the assignment of shelter. In the present model, the total population of a grid element is the basic decision unit and receives a uniform level of protection. This procedure does not generally permit the allocation of shelter in the most economica sequence or priority, given the existence of budgetary constraint For example, if grid elements were not treated as indivisible, shelters of the most economical size, e.g., 1,000-man occupancy, could be utilized to the maximum extent possible before allocatir any of the smaller shelters which are now necessary to provide full protection for all the people in an element. Alternatively, sparsely populated elements could be joined together for protection purposes in order to permit more efficient shelter assignmer

Clearly, a program that would allocate different protection level to different populations within the same area has important social and political implications which must be understood and accommodated befor shelters could be constructed and installed. Equitable and politicall acceptable allocation is only one problem. Feasible shelter sites would have to be identified through engineering surveys; and property ownership problems, including rights-of-way, would have to be resolved before sites could be selected. A model such as that presented in thi Study would be an invaluable tool for evaluating alternative courses and decisions at each point in the development of this type of operating program.

Appendix A

GLOSSARY OF NOTATION

Appendix A

GLOSSARY OF NOTATION

a_{ij}: Matrix element in the i-th row, j-th column being evaluated for vulnerability or sheltering

a_{mn}: Matrix element in the m-th row, n-th column being evaluated as an Actual Ground Zero (AGZ)

c_{ijk}: Average cost per space for protecting the population in the i-, j-th element with k strength shelter. This average cost reflects the most economical combination of shelter sizes that will accommodate that number of people.

d_{ij}: Distance of an element, a_{ij}, from the target element, a_{mn}

$$d_{ij} = \sqrt{(i-m)^2 + (j-n)^2}$$

$f_k = \alpha_n - V_{mn}$: The allowable fatalities in R_k

$P_o = \sum_{R_o} p_{ij}$: The sum of the population in the unprotectable region, R_o

$P_1 = \sum_{R_o} p_{ij} + \sum_{R_o} p_{ij}$: The sum of the population within r_1

p_{ij}: Population in element a_{ij}

R_k: A region within which k shelter strength will protect and a lower psi shelter will not ($k = 0, 1, 2, \ldots, N$) in relation to a specific AGZ

R_o: Region about AGZ within which strongest shelter under consideration (s_1) will not provide adequate blast protection against a given yield weapon. R_o contains all matrix elements i,j located at distances from ground zero where the blast overpressure is greater than the psi rating of the strongest shelter under consideration

r_k: Outer limit of R_k as a distance from ground zero

r_o: Outer limit of R_o as a distance from ground zero

s_k: Shelter strength being allocated (k = 1 for the strongest shelter, 2 for the next strongest, etc

$U_k = \sum_{R_k} u_{ij}$: The total unprotected population within region R

u_{ij}: Population p_{ij} of an element a_{ij} which does not have adequate blast protection, e.g., the population of an element in R_2 which does not have s_2 or stronger (s_1) shelter

V_{mn}: The vulnerable population with respect to a given ground zero, a_{mn}, that is unprotectable with the shelter strength, s_k, being allocated

$$V_{mn} = P_o + U_1 + U_2 + \ldots + U_{k-1}$$

α_n: The level at which fatalities are to be upper bounded (n = 1, 2, ..., m)

α_1: The minimum level at which fatalities can be upper-bounded with the strongest shelter, s_1, under consideration

α_m: The maximum fatality level for which at least some of the strongest shelters, s_1, would be required.

Appendix B

SPECIFICATIONS FOR PROGRAM DAMIT

Appendix B

SPECIFICATIONS FOR PROGRAM DAMIT[1]

This appendix describes the shelter allocation model in sufficient detail to provide a more thorough understanding of the basic process and to facilitate computer programming. Although these specifications incorporate refinements to the initial computer program (ALLOCATE) used for the studies presented in Section III, the basic allocation procedures are identical.

The main flow of Program DAMIT is presented in Figure B-1. The remainder of this appendix is devoted to a detailed description of the steps depicted in this diagram.

I. INPUT ROUTINE (Figure B-2)

I-A. Population Matrix

A magnetic tape containing the population matrix should be prepared. All pertinent dimension statements should be modified to conform to the size of the population matrix. Total population should be computed immediately and stored for later use.

I-B. Data Card(s) 1

These are cards containing alphamerical descriptions of the problem. Example: "1960 HOUSTON NIGHTTIME POPULATION." This can be simplified by assigning problem identification numbers.

I-C. Data Card 2

Columns 1-5 : Number of rows in population matrix.
6-10: Number of columns in population matrix.
11-15: Number of shelter strengths in posture.

1. DAMage limITing strategy.

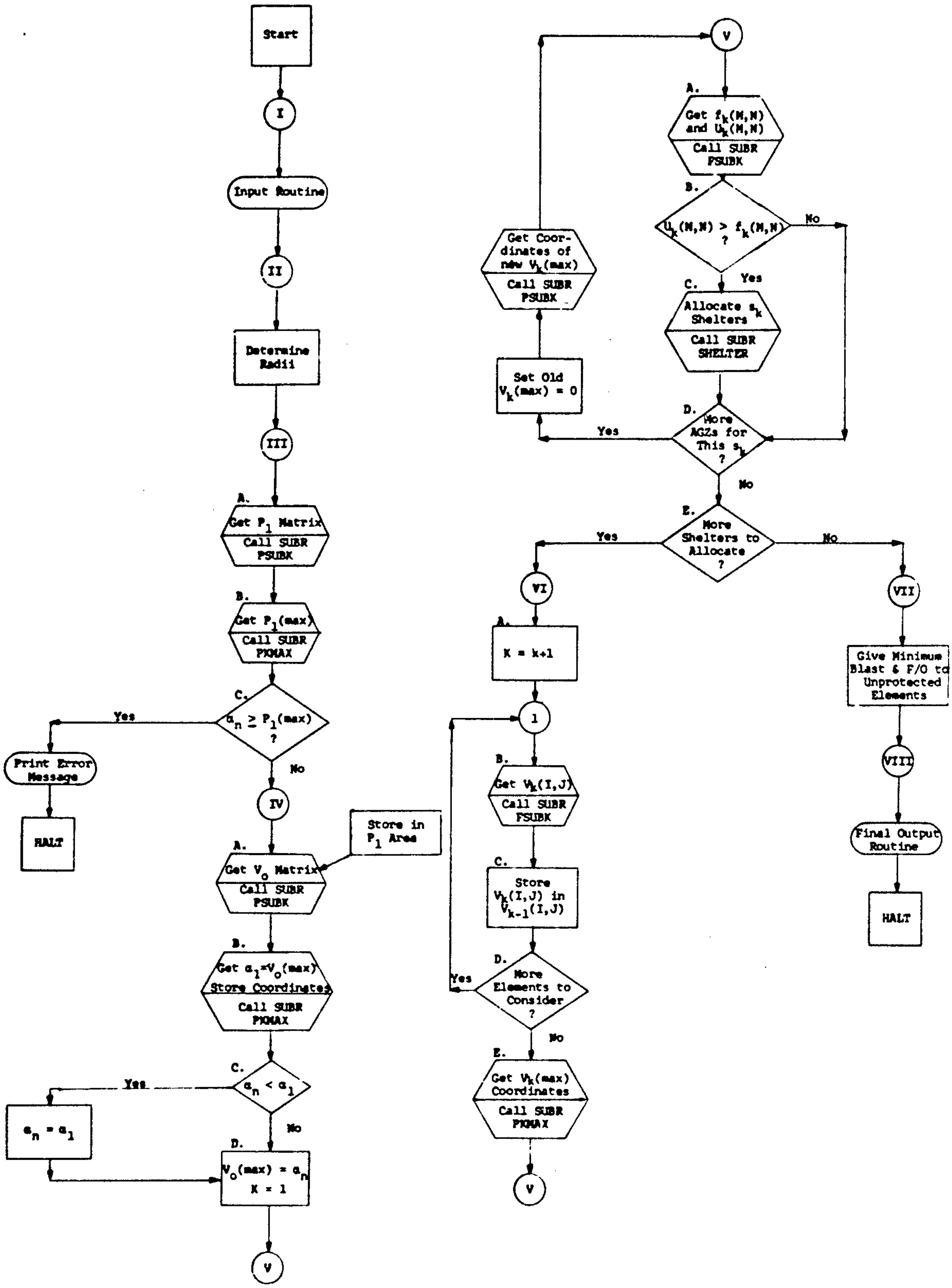


FIGURE B-1 Main Flow of Program DAMIT

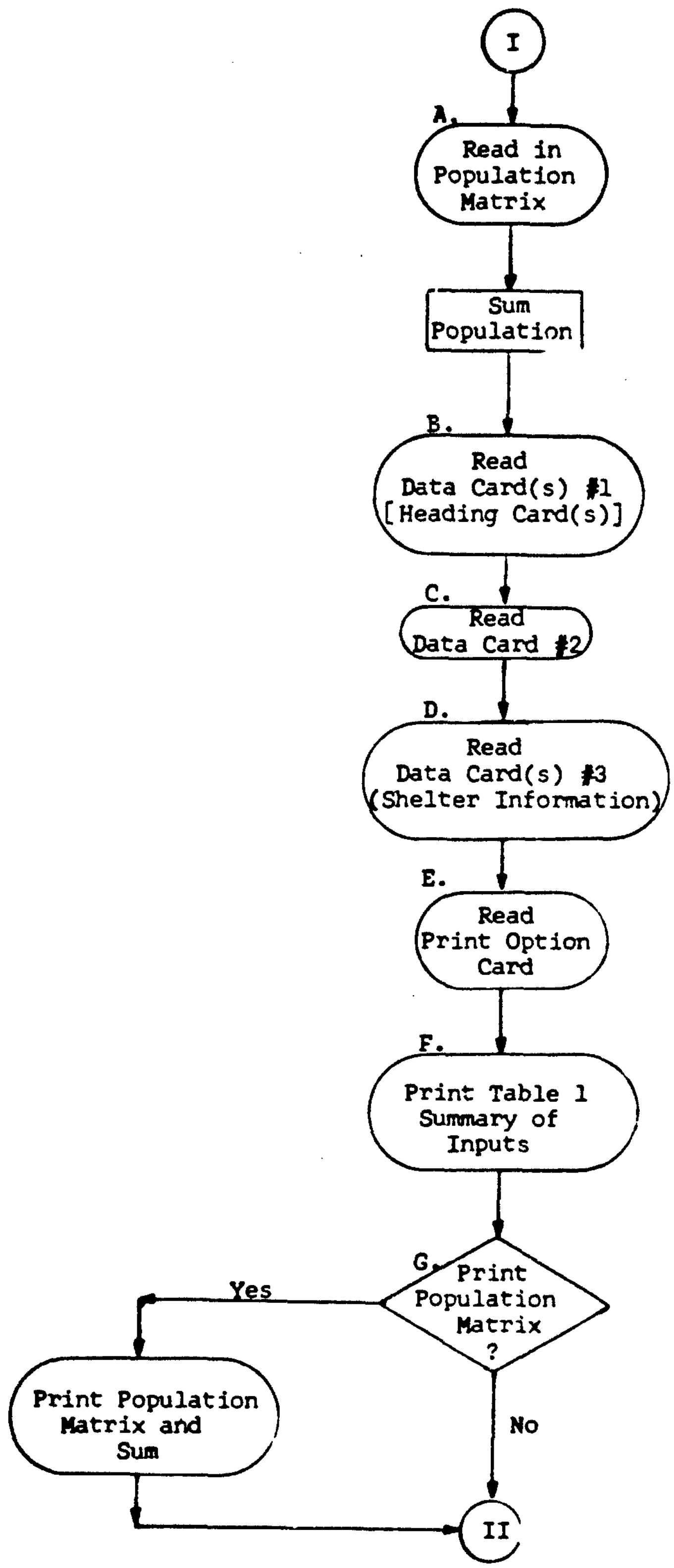


FIGURE B-2 Input Routine

16-20: Weapon yield (megatons).

21-25: Prescribed fatality level (α_{11}) in percent.

26-30: Blast protection level (psi) given to fallout shelters.

31-40: Cost per person of fallout shelters.

I-D. Data Card 3--Shelter Information Card(s)

For maximum input flexibility, there should be one card for each shelter size.

Columns 1-5 : Shelter strength (psi).

6-10: Shelter size (number of persons capacity).

11-20: Shelter cost (nearest dollar).

I-E. Print Option Card

This program should permit the examination of output at critical stages of the various iterative processes. This will maximize the research potential of the program.

Each column of the print option card represents a particular table in the program. A "0" in a column indicates that the table is not to be printed. A "1" in the column specifies that it is to be printed.

Certain tables such as the summary of inputs and the final shelter posture should be printed automatically.

I-F. Table 1.00--Summary of Inputs

This table indicates all information on data cards 1, 2 and 3.

I-G. Table 1.01--Population Matrix (optional)

This table is a printout of the population matrix. The total population should be printed beneath the table heading.[1]

---

1. See Subroutine PRINT1 in the Civil Defense Project Subroutine Library Manual. This publication will henceforth be abbreviated as CDPSLM.

II. DETERMINATION OF PSI RADII (Figure B-3)[1]

This portion of the program determines the distance from a given ground zero that a shelter of a certain strength will be effective. These are the r_k, i.e., the outer limits of the region within which a given strength shelter in the posture will protect and a lower strength shelter in the posture will not.

II-A. Prepare Psi Array

The shelter strengths read in at Steps I-C and I-D are collected into an array in descending order of magnitude. The number of radii to be computed must also be determined.

II-B. Call Subroutine RADIUS

A description of this subroutine may be found in the CDPSLM. The arguments for this subroutine are

(1) Number of radii required
(2) Array of radii (output)
(3) Psi array (input)
(4) Yield (megatons)

II-C. Store Radii

The array of radii should be stored for later used in the program.

II-D. Print (optionally) psi and radii.

III. TEST FOR CONSISTENCY OF INPUT (Figure B-1)[2]

The fatality level, α_n, inputted via data card 2 must be consistent with the shelter configuration prescribed on the shelter information cards. If α_n is so large that the highest shelter strength inputted would not be allocated, a great deal of computer

1. This represents a modification of the operational version of the Program (ALLOCATE) where the radii are required as input.

2. This represents a modification of Program ALLOCATE, where no such test is made.

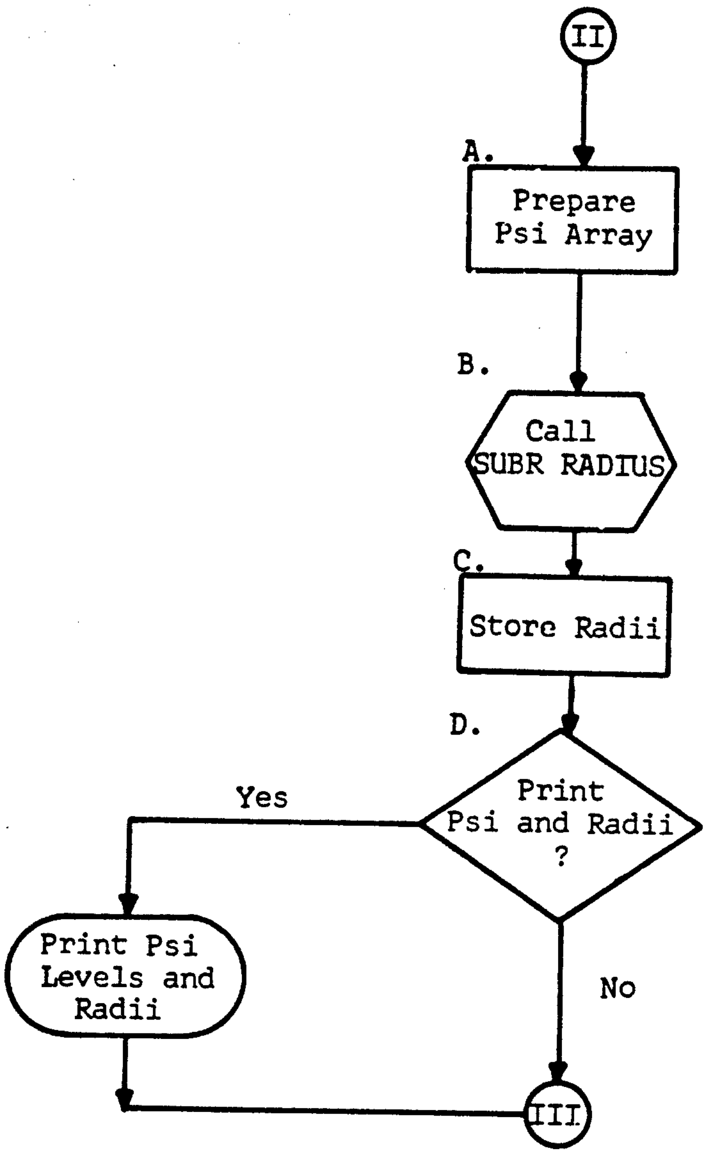


FIGURE B-3 Determination of psi Radii

time would be wasted in trying to allocate the highest strength shelters when such shelters are actually not needed. This test eliminates this possibility by printing out an error message and halting the operation if the specified fatality level is equal to or greater than the upper bound of fatalities associated with the next highest strength shelter.

III-A. Determine P_1 Matrix

P_1 is the population in the region around a given ground zero within which the next-to-strongest shelter in the posture will not provide adequate blast protection against a given yield weapon. The P_1 matrix represents the set of P_1 values determined when each element in the population matrix is assumed to be the target. For example, Table B-1 presents a hypothetical 5 x 5 population matrix. One kilometer separates each adjacent element. Suppose that element (3,3) is regarded as the ground zero and that the distance within which no protection can be given by the next-to-highest strength shelter available is one kilometer. This means that the population in elements (2,3), (3,2), (3,3), (3,4), and (4,3) cannot be protected $P_1(3,3) = 21$. All other elements are at a distance greater than one kilometer from ground zero (3,3). P_1 (3,3) is entered into Table B-2 and circled.

Table B-1

Population Matrix

I \ J	1	2	3	4	5
1	1	1	1	2	1
2	2	1	3	3	1
3	0	5	5	4	3
4	1	4	4	4	2
5	2	3	2	2	1

Now suppose that element (1,1) is the ground zero. The population one kilometer or less from this target is represented by elements (1,1), (1,2), and (2,1). Therefore, P_1 (1,1) = 4, and this

value is circled in Table B-2. In the same fashion, all other elements are assumed to be ground zeros and the values of P_1 (I,J) determined. Subroutine PSUBK is designed to obtain the P_1 matrix. More generally, it is designed to obtain any such matrix, P_k, where the population within a given radius from each possible ground zero is to be determined.[1]

Table B-2

P_1 Matrix

I \ J	1	2	3	4	5
1	4	4	7	7	4
2	4	12	13	13	8
3	8	15	21	19	10
4	7	17	19	16	10
5	6	11	11	9	5

III-B. Determine P_1(MAX)

Subroutine PKMAX uses the P_k matrix as input and determines the maximum value in the matrix.[2] In the above example, $P_1(MAX) = 21$, and this would be the output of the routine.

III-C. Test if α_n Is Greater than or Equal to P_1(MAX)

If the inputted fatality level α_n is greater than or equal to P_1(MAX), then the program would unnecessarily attempt to allocate the highest strength shelter and computer time would be wasted. To prevent this, the following error message should be printed (off line) if this condition exists:

> "P1(MAX) = ___. INPUTTED FATALITY LEVEL = ___ WHICH IS GREATER THAN OR EQUAL TO P1(MAX). NO S1 SHELTERS CAN BE ALLOCATED. CHANGE EITHER ALPHA N LEVEL OR STRENGTH OF S1 SHELTER."

The program should be terminated after this message is printed.

1. See Subroutine PSUBK in the CDPSLM.
2. See Subroutine PKMAX in the CDPSLM.

IV. SET UP INITIAL CONDITIONS FOR LOOP ENTRY

The allocation begins at the element with the maximum unprotectable population level. In this case, the V_o matrix is identical to the P_o matrix and $V_o(MAX) = P_o(MAX) = \alpha_1$.

IV-A. Determine V_o Matrix

Here Subroutine PSUBK can be called again using as input the radius within which no person can be protected by the highest strength shelter.[1]

IV-B. Determine α_1

Subroutine PKMAX may be used to obtain $V_o(MAX) = \alpha_1$. The coordinate of this maximum must be stored for use in the allocation loop. α_1 should be stored for final output.

IV-C. Test if α_n Is Less than α_1

If the inputted fatality level, α_n, is less than α_1, then it is assumed that α_1 is the fatality level prescribed, for it is impossible to guarantee fatalities below the α_1 level.

IV-D. Initialize $V_o(MAX)$ and K

$V_o(MAX)$ is set to α_n and K is set equal to 1.

V. ALLOCATE SHELTERS OF STRENGTH s_k

Part V represents the shelter allocation loop. The individual steps are described in detail below.

V-A. Determine $f_k(M,M)$ and $U_k(M,N)$

Subroutine FSUBK (see Figure B-4) is designed to obtain for a specific target (1) f_k = the number of persons that may be left unsheltered without exceeding the fatality limit, (2) U_k = the number of persons in the protectable region that have not been given adequate shelters, and (3) $V_k = P_o + U_k$, where P_o is the population that cannot be protected even with the highest strength shelter. V_k may be thought of as the "vulnerable" population.

---

1. The P_1 matrix is no longer needed. Store V_o in the same area.

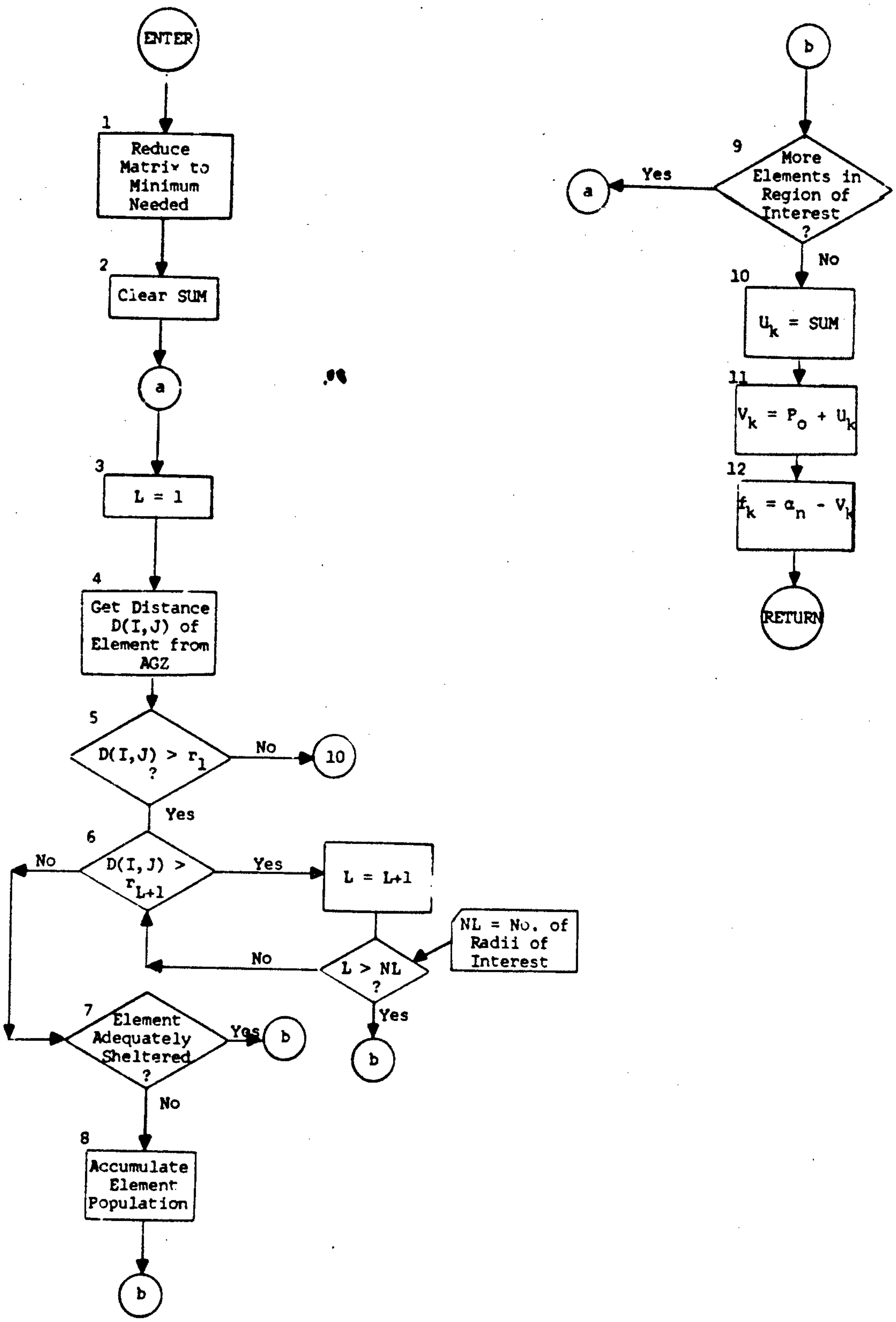


FIGURE B-4 Subroutine FSUBK

The arguments to the subroutine are as follows:

Inputs

M: Row coordinate of the ground zero of interest

N: Column coordinate of the ground zero of interest

NR: Number of rows in population matrix

NC: Number of columns in population matrix

$P_o(M,N)$: Unprotectable population for ground zero of interest

NL: Number of radii to be considered (= K + 1)

RAD: Array of radii computed in Step II

SHELT: Array of assigned shelter strengths

POP: Population array

SK: Strength of shelter being allocated

AN: Maximum allowable fatalities, α_n

Outputs

F: f_k = allowable fatalities

U: U_k = unprotected population in protectable region

V: V_k = vulnerable population

The basic steps of the routine are:

Step 1: Reduce Matrix to Minimum Needed. Nearly all elements whose distances are greater than the largest inputted radius, RAD(NJ), are eliminated from consideration. Precautions are taken to ensure that the limits of the reduced matrix are within the population matrix.

Step 2: Clear SUM (accumulator for U_k computation).

Step 3: L = 1. The first radius to consider is RAD(1) = r_o. L is the radius index. We are now in the unprotected population accumulation loop, starting at the upper left-hand coordinates of the reduced matrix.

Step 4: Determine the Distance of the Center of the Element from the Ground Zero.

$$D(I,J) = \sqrt{(I - M)^2 + (J - N)^2}$$

Step 5: Test if $D(I,J) > RAD(L) = RAD(L) = r_o$. If this distance is equal to or less than RAD(1), then the element is in the unprotectable region, and its population would be included in $P_o(M,N)$. If it is greater than RAD(1), the next test must be made.

Step 6: Test if $D(I,J) > RAD(L + 1)$. At the first iteration, the test determines whether $D(I,J) > RAD(2) = r_1$. If it is, then it tests whether $D(I,J) > RAD(3) = r_2$, and so on until the largest radius, RAD(NL) to be considered has been reached. If the distance is greater than RAD(NL), the element is outside the region of interest, and the program branches to Step 9. If the element is within the region of interest, control goes to Step 7.

Step 7: Test if Element is Adequately Sneltered. Using the array of assigned shelters, test to determine whether a shelter strength that may have been assigned to the element when other targets were considered is strong enough to withstand the psi level it will encounter for this ground zero. If it is, the population in the element is adequately sheltered for the ground zero under consideration. If it is not, control goes to Step 8.

Step 8: Accumulate Unprotected Population.

Step 9. Test if More Elements Are to be Considered. If yes, L is restored to equal 1, and a new element in the reduced matrix is considered. If no, go to Step 10.

Step 10: $U_k(M,N)$ = the Sum of the Unprotected Population, SUM.

Step 11: $V_k(M,N)$ = the Vulnerable Population = $P_o(M,N) + U_k(M,N)$.

Step 12: $f_k(M,N)$ = Allowable Fatalities = $\alpha_n - V_k(M,N)$.

V-B. Test if $U_k(M,N) > f_k(M,N)$

If the unprotected population in the protectable region is greater than the allowable fatalities, then enough s_k shelters must be assigned to keep fatalities within the bounds of α_n and the program goes to step V-C. If $U_k(M,N) \leq f_k(M,N)$ then no s_k shelters need to be allocated to keep fatalities within the bounds of α_n; therefore, the program skips to step V-D.

V-C. Allocate s_k Shelters

Subroutine SHELTER (see Figure B-5) is designed to allocate shelters of a given strength and given capacities to the population of a region around a prescribed ground zero where the shelter strength is adequate to protect the population. The routine assigns shelters only up to a specified population level within the region and assignments are made to those elements where the average cost per person is smallest.[1] Subroutine MINLCOST is used to determine the average cost per person of each element in the region.

The arguments for Subroutine SHELTER are as follows:

Inputs

II: Row coordinates of ground zero
JJ: Column coordinates of ground zero
R1: Inner radius of region of interest (kilometers)
R2: Outer radius of region of interest (kilometers)
NC: Number of columns in population matrix
NR: Number of rows in population matrix
IALF: Allowable fatalities for this region
JSS: Shelter strength of shelters being allocated
NSM: Smallest size shelter in the shelter size array
NSS: Number of shelters in the shelter size array
JSIZ: Shelter size array
JCOST: Shelter cost array
IPOP: Population array
IWORK1: Dummy work area
IWORK2: Dummy work area
IWORK3: Dummy work area
IWORK4: Dummy work area
IWORK5: Dummy work area
IWORK6: Dummy work area
NRNC: NR times NC

---

1. This represents a modification of Program ALLOCATE, where the average cost per required space is utilized.

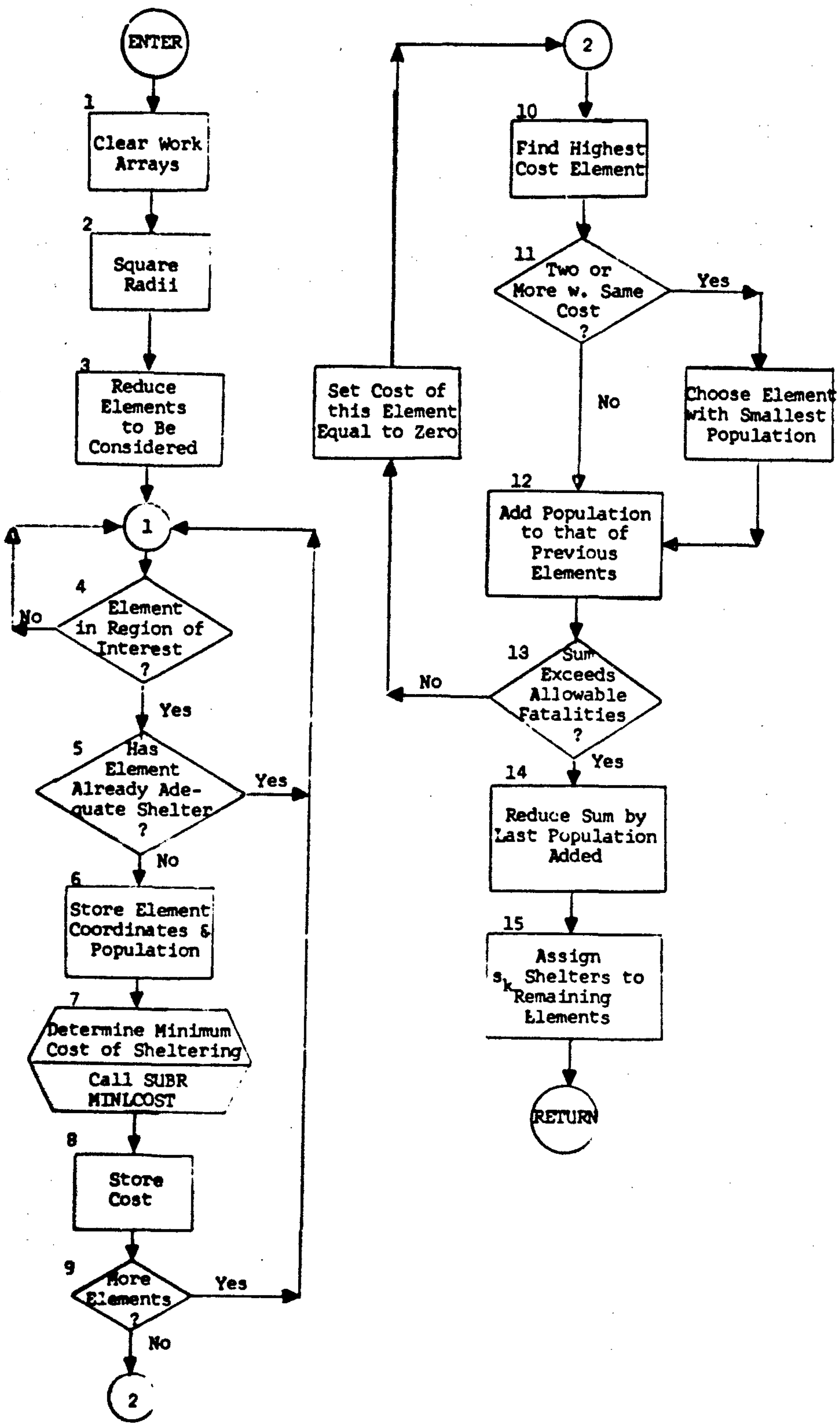


FIGURE B-5 Subroutine Shelter

Output

MSHELT: Shelter strength array

Figure B-5 indicates the procedure.

Step 1: All work arrays are cleared and variables initialized where necessary.

Step 2: The two inputted radii are squared.

Step 3: The size of the population matrix is reduced to approximately those elements whose distances are equal to or within the outer radius, r_2, from the inputted ground zero. Precautions are taken to ensure that the limits of the reduced matrix are within the population matrix.

Step 4: If the square of the distance of the center of the element is greater than r_1^2 and less than or equal to r^2, the element is in the region of interest and the next instruction is at Step 5. Otherwise, the next element is considered.

Step 5: The element is tested to determine whether it has already been assigned adequate shelter. If not, the next instruction is at Step 6. Otherwise, the next element is considered.

Step 6: The population and coordinates are stored in two corresponding arrays.

Step 7: The minimum average cost per person is determined using Subroutine MINLCOST. This routine (see Figure B-6) is designed to determine the average cost per person of sheltering the population of an element using that combination of shelter sizes and costs that will yield the minimum cost per person. The routine also returns the shelter size distribution that yields the minimum cost per person.

The arguments for Subroutine MINLCOST are as follows:

Inputs

NPOP: Population to be sheltered

NSM: Smallest size shelter in the array of shelter sizes

NSS: Number of shelter sizes in the array of shelter sizes

NSIZ: Shelter size array

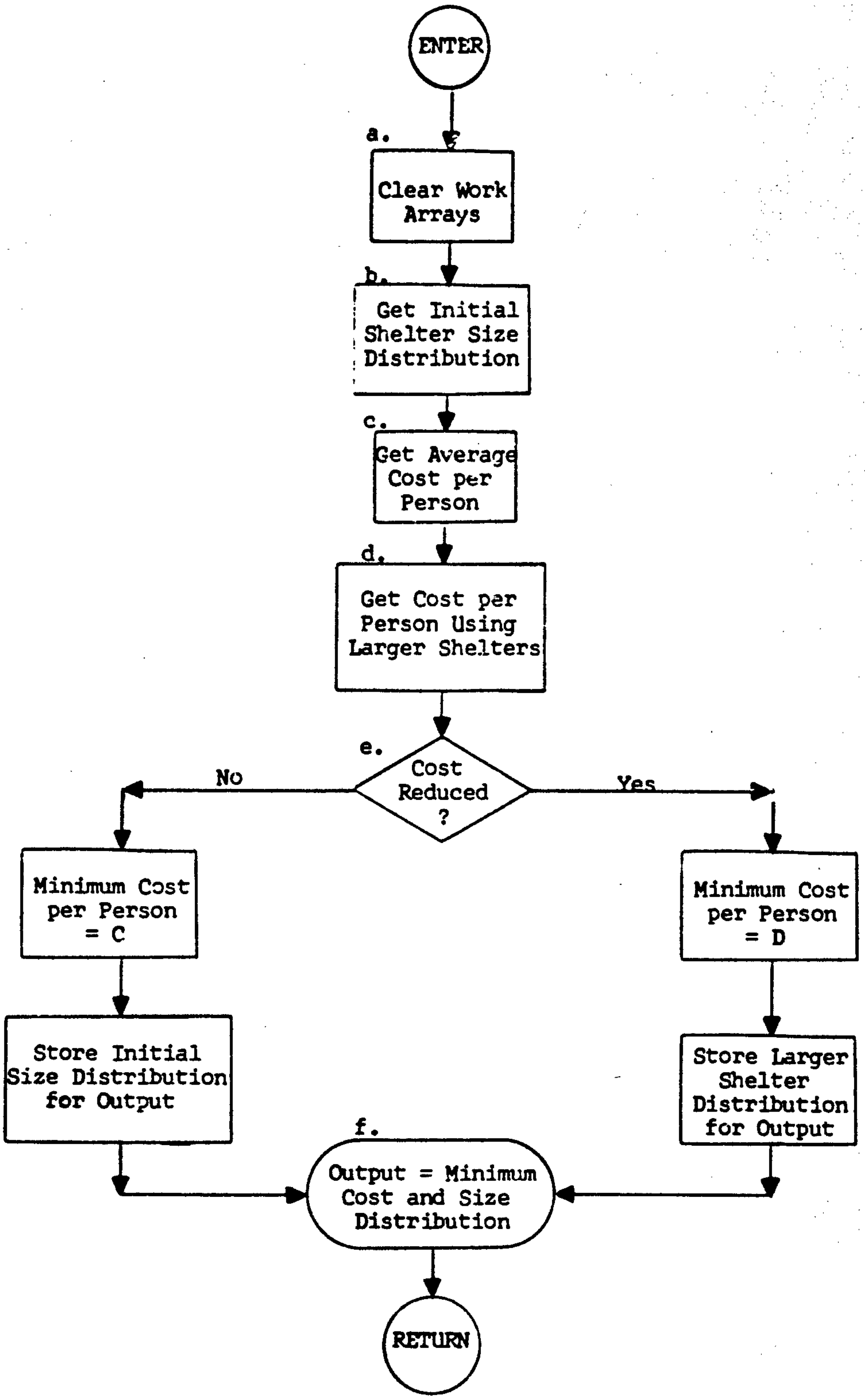


FIGURE B-6 Subroutine Minlcost

NCOST: Shelter cost array

IWORK4: Dummy work array

JA: Dummy work array

IWORK7: Dummy work array

Outputs

ISIZE: Array giving number of shelters of each size that yields minimum average cost

MIN: Minimum cost per person

Figure B-6 indicates the procedure

(1) All work and output areas are cleared.

(2) The initial size distribution is determined by:

(a) Assigning the largest size shelter until population is exceeded;

(b) Reducing the number of largest size shelters by one and assigning the next largest to the remaining population until this remainder is exceeded;

(c) Reducing the number of the next-to-largest shelters by one and assigning the next size shelter to the remainder, and so on.

(3) The total cost of the resulting shelter size distribution is determined and divided by the size of population.

(4) The average cost of using a larger shelter instead of several smaller ones is determined. For example, one 500-man shelter may be used instead of four 100-man shelters.

(5) This is compared with the initial average. If the alternative cost is smaller, the initial shelter distribution is replaced by the new distribution. Subsequent costs and distributions are compared with the results of previous iterations.

(6) The subroutine returns the minimum cost determined in (5) and the final size distribution yielding this cost.

Step 8; This cost is stored in an array.

Step 9: If more elements are i- the matrix, Steps 4 through 8 are repeated. Otherwise, the routine goes to Step 10.

Step 10: The cost array is searched for the highest cost element.

Step 11: If two or more elements have equally high costs, the one with the smallest population is chosen.

Step 12: The highest cost elements are accumulated, until

Step 13: The sum exceeds the allowable fatalities, IALF.

Step 14: The population of the last element added is subtracted from this sum.

Step 15: The population in the remaining elements in the population array is given shelter protection of strength JSS. This is stored in the array called MSHELT, and the routine returns to the calling program.

V-D. Test if There Are More Ground Zeros for Given s_k

If all possible ground zeros have not been considered, the ground zero with the next highest vulnerability in the V_k matrix (as determined at either Step IV-A or VI-B) is chosen. This is accomplished by first setting the old maximum to zero and then using Subroutine PKMAX to determine the coordinates of the new maximum.

V-E. Test if There Are More Shelters to Allocate

If all of the shelter strengths have not been allocated, the program goes to Step VI. If all have been allocated, the program goes to Step VII.

VI. DETERMINATION OF NEW V_k MATRIX

When the next strength shelter is to be allocated, a new vulnerability matrix must be obtained. This is accomplished by successive application of Subroutine FSUBK (Step VI-B) and replacing the old V_{k-1} values with the new V_k values (Step VI-C). When all of the V_k values have been computed, the coordinates of the maximum value of the V_k matrix are obtained. This is the first ground zero for the new shelter allocation. Control returns to Step V.

VII. GIVE MINIMUM BLAST AND FALLOUT PROTECTION TO UNPROTECTED ELEMENTS

Minimum blast and fallout protection are given to all elements not receiving higher than minimum shelters. The level of the minimum is specified in data card 2.

VIII. FINAL OUTPUT ROUTINE (Figure B-7)

VIII-A. Print Final Shelter Strength Posture (optionally)

VIII-B. Write Final Shelter Matrix on Tape

The final shelter posture is written on tape with proper labeling.

VIII-C. Print Details for Each Element (optionally)

If the option is exercised, the indicated list is printed. In any case, the details are written on tape.

VIII-D. Print Final Summary of Posture

This is not an optional step. It is assumed that this will always be desired information.

VIII-E. Write Summary Information on Tape

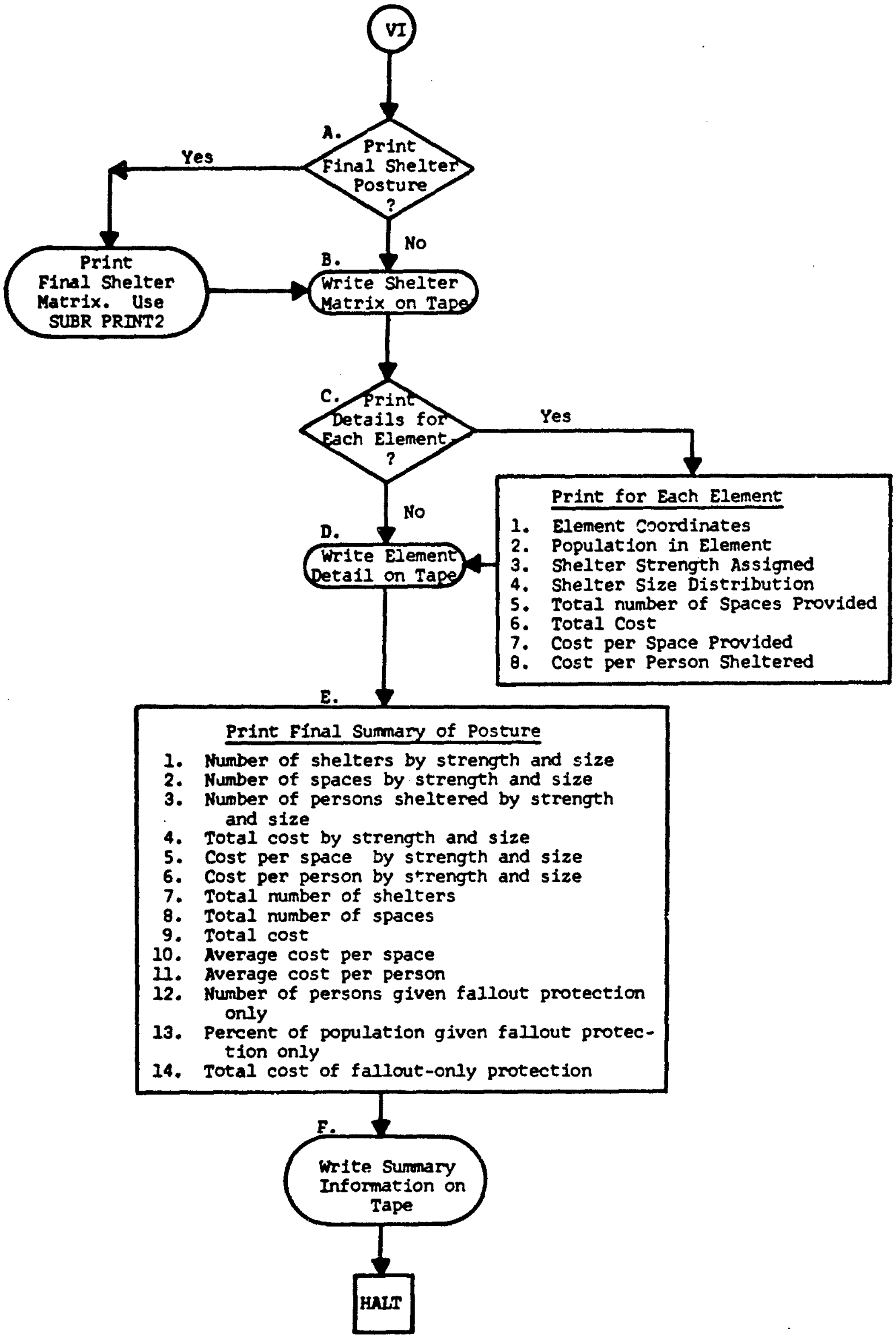


FIGURE B-7 Final Output Routine

Appendix C

SHELTER COSTS

Appendix C

SHELTER COSTS

The cost data used in the development and costing of alternative shelter postures for Houston, Texas, are as follows:

Blast Shelters	Total Cost	Cost Per Space
35 psi		
100-man	$ 49,557	$ 496
500-man	165,624	331
1000-man	324,576	325
100 psi		
100-man	58,060	581
500-man	195,055	390
1000-man	379,147	379
300 psi		
100-man	77,067	71

C1. FALLOUT SHELTERS

The 657,745 additional spaces required under a full fallout shelter program for Houston are estimated to cost an average of $85 per space. The OSA(CD) minimum criteria for fallout shelters is PF = 40. These spaces would be located in buildings, specifically hospitals and schools, which are of light steel-frame construction in Houston.

C2. DATA SOURCES

The above shelter costs were developed by the IDA Civil Defense Project Group in 1964 for use in local area studies focused on Houston. The detailed data base including specific sources is available but as yet unpublished. Specific queries in this regard

may be directed to the Head, Civil Defense Project, Economic and Political Studies Division, Institute for Defense Analyses, 400 Army-Navy Drive, Arlington, Virginia.

C3. COST PER REQUIRED SPACE

The element-by-element differences in cost per required space are illustrated below for four elements requiring 100-psi protection in reference to a particular ground zero.

Population	Required Number Spaces[a]	Most Efficient Shelter Mix		Shelter Cost			Relative Priority for Shelter Allocation[b]
		No.	Occupancy	Unit	Total	Per Space	
810	900	1	1,000[c]	$379,147	$379,147	$421	(3)
995	1,000	1	1,000	379,147	379,147	379	(1)
1,130	1,200	1	1,000	379,147	379,147		
	plus	2	100	58,060	116,120		
					$495,267	413	(2)
700	700	1	500	195,055	195,055		
	plus	2	100	58,060	116,120		
					$311,175	444	(4)

a. Populations are rounded up to the next hundred for this purpose because all shelter occupancies are in hundreds.

b. Should a choice exist between two elements having the same cost per required shelter space, the model gives priority for sheltering to the one of highest population density. This rule anticipates potential cost savings for larger versus smaller shelter complexes.

c. The choice of 100-psi shelter sizes is 100-, 500- or 1,000-man. As can be deduced from the sample data shown, a 1,000-man shelter is more economical than a one-500/four-100-man mix for sheltering elements having 801 to 900 population.

APPENDIX D

SPACES AND COST DATA

FOR MOST EFFICIENT SHELTER POSTURES

APPENDIX D

SPACES AND COST DATA FOR MOST EFFICIENT SHELTER POSTURES

(Designed to Counter a Single 10-Mt Surface Burst on the Houston At-Home Population)

Percent Minimum Survival	Type Shelter	Persons Sheltered, Thousands	Spaces Required[a], Thousands	Spaces Provided[b], Thousands	Total Cost, Millions of $
65	100-psi	52	53	53	20
	Fallout[c]	1,174	1,174	1,174	100
	Total	1,226	1,227	1,227	120
70	100-psi	131	133	133	51
	Fallout	1,095	1,095	1,095	93
	Total	1,226	1,228	1,228	144
80	100-psi	317	321	322	123
	Fallout	909	909	909	77
	Total	1,226	1,230	1,231	201
90	100-psi	620	631	635	245
	Fallout	606	606	606	52
	Total	1,226	1,237	1,241	296
95	100-psi	912	932	941	367
	Fallout	314	314	314	27
	Total	1,226	1,246	1,255	393
98	300-psi	229	232	232	179
	100-psi	860	889	902	358
	Fallout	137	137	137	11
	Total	1,226	1,258	1,271	548

a. Population in each grid element is rounded to next 100.
b. Additional spaces are provided if larger shelters are more economical for meeting the requirement.
c. 7.3-psi, PF = 40.